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Felts

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(54) **CONTINUOUS SYSTEM FOR DEPOSITING FILMS ONTO PLASTIC BOTTLES AND METHOD**

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(51) **Int. Cl.**

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C23C 16/455	(2006.01)
C23C 16/458	(2006.01)
C23C 16/50	(2006.01)
C23C 16/503	(2006.01)
C23C 16/54	(2006.01)

(52) **U.S. Cl.** .... **118/719**; 118/715; 118/723 R; 118/723 E; 118/729; 118/730

(58) **Field of Classification Search** .... 118/715, 118/719, 723 R, 723 E, 728–730, 50.1; 156/345.31, 156/345.33, 345.43, 345.44, 345.51, 345.54, 156/345.55

See application file for complete search history.

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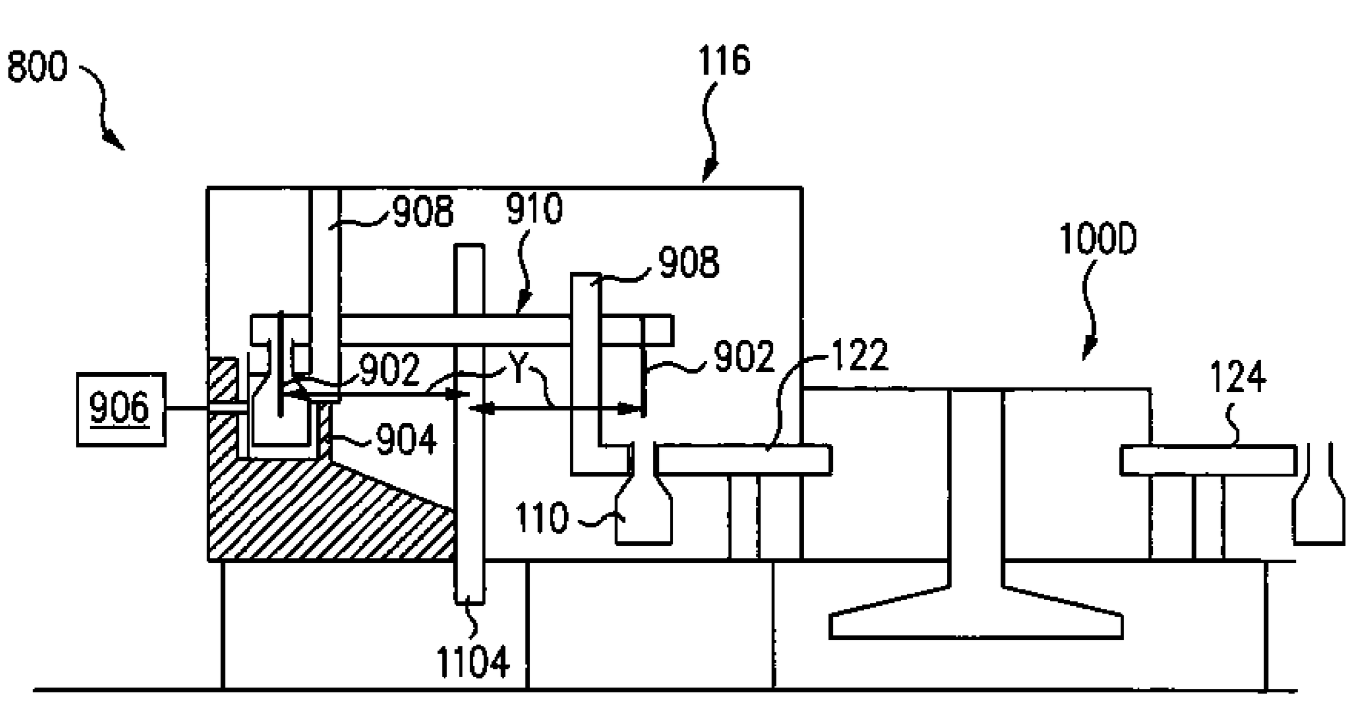
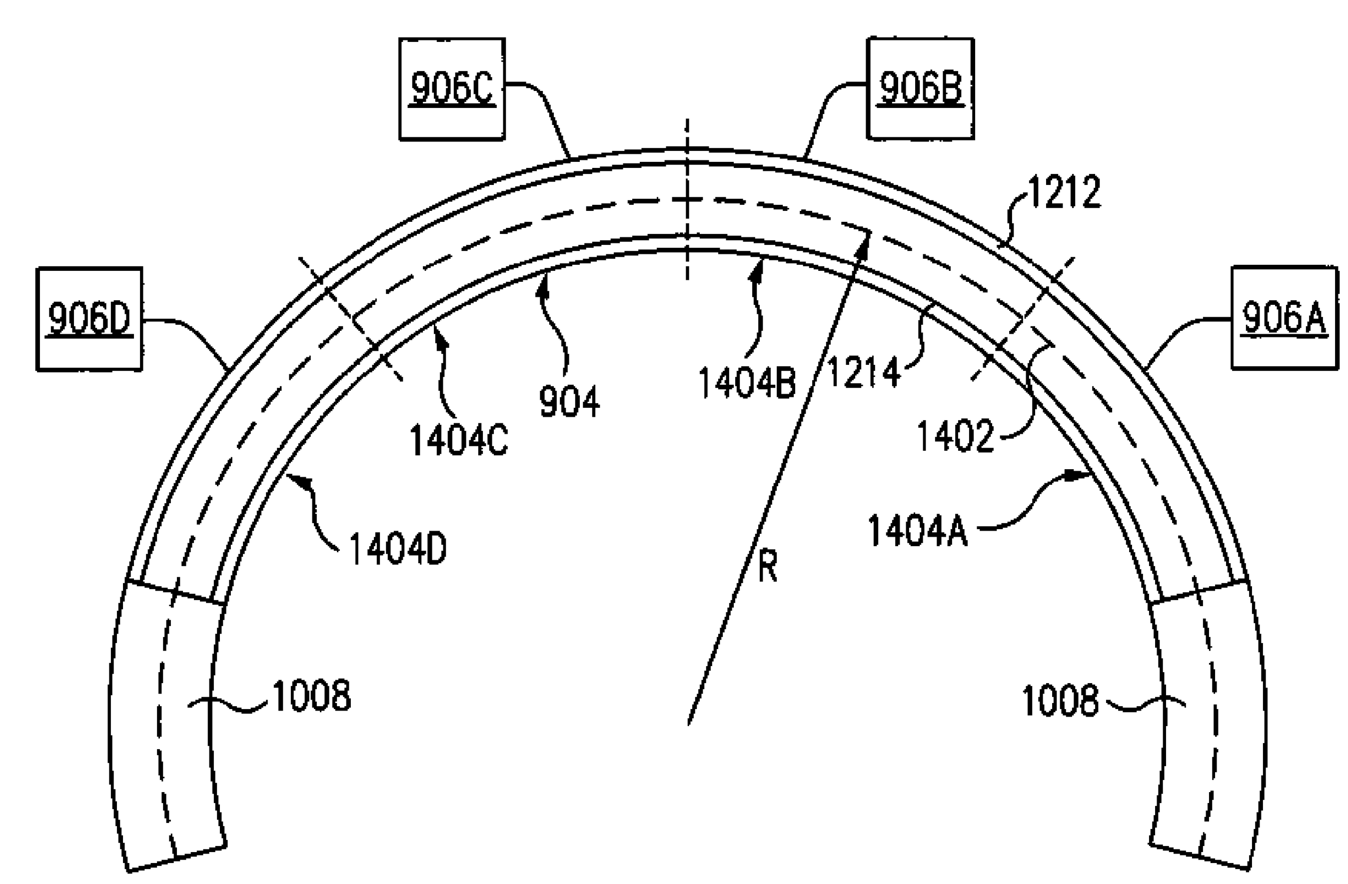
(57) **ABSTRACT**

A bottle processing apparatus includes a rotary bottle vacuum transfer system and a bottle coating system. The rotary bottle vacuum transfer system takes bottles from atmospheric pressure and transfers the bottles to the bottle coating system at a sub-atmospheric pressure in a continuous assembly line fashion. In the bottle coating system, a thin film coating having barrier properties is formed on at least one surface of the bottles in a continuous assembly line fashion. After formation of the thin film coating, the rotary bottle vacuum transfer system returns the bottles from the sub-atmospheric pressure region of the bottle coating system back to atmospheric pressure in a continuous assembly line fashion.

21 Claims, 9 Drawing Sheets





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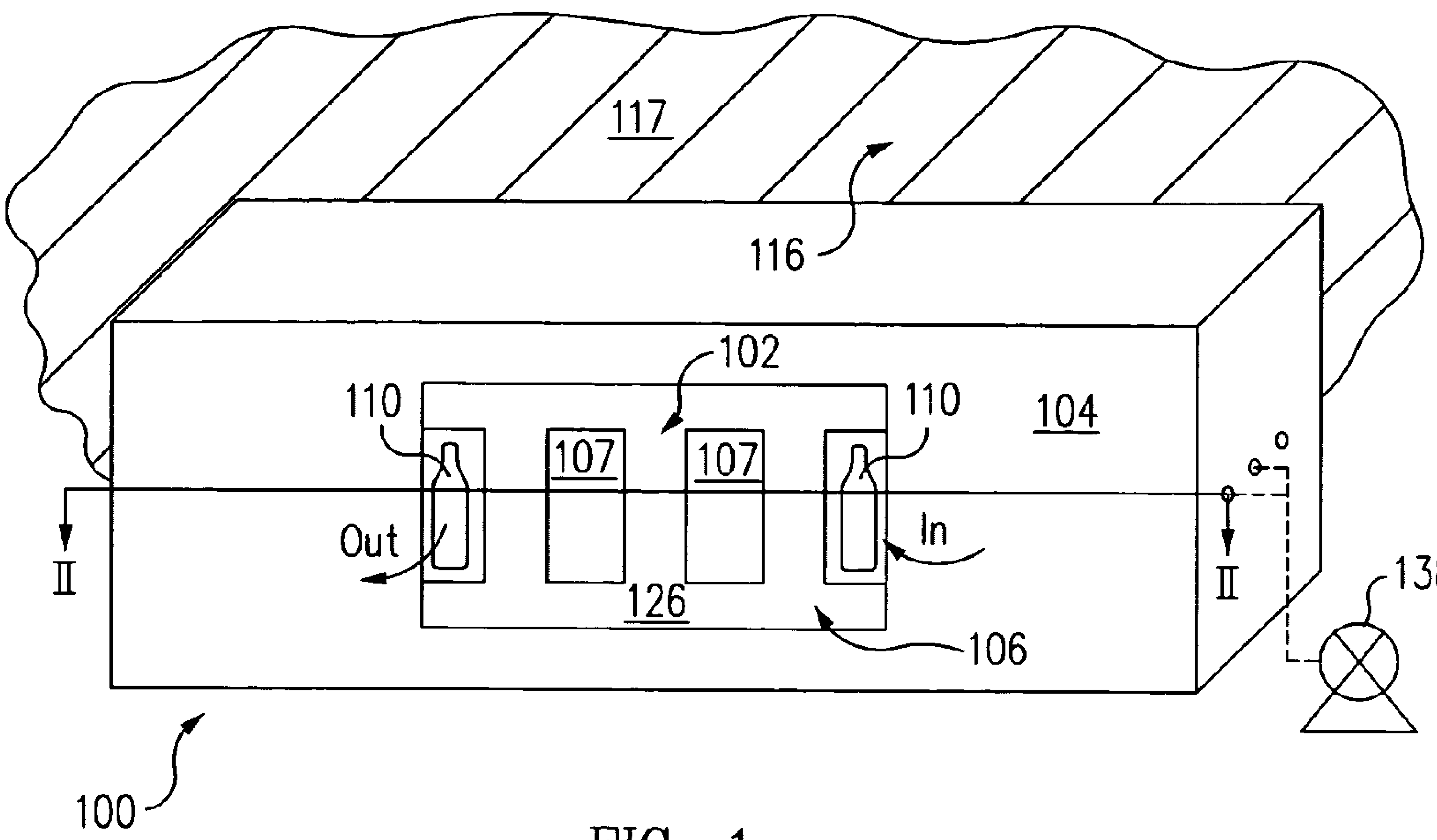
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II
II
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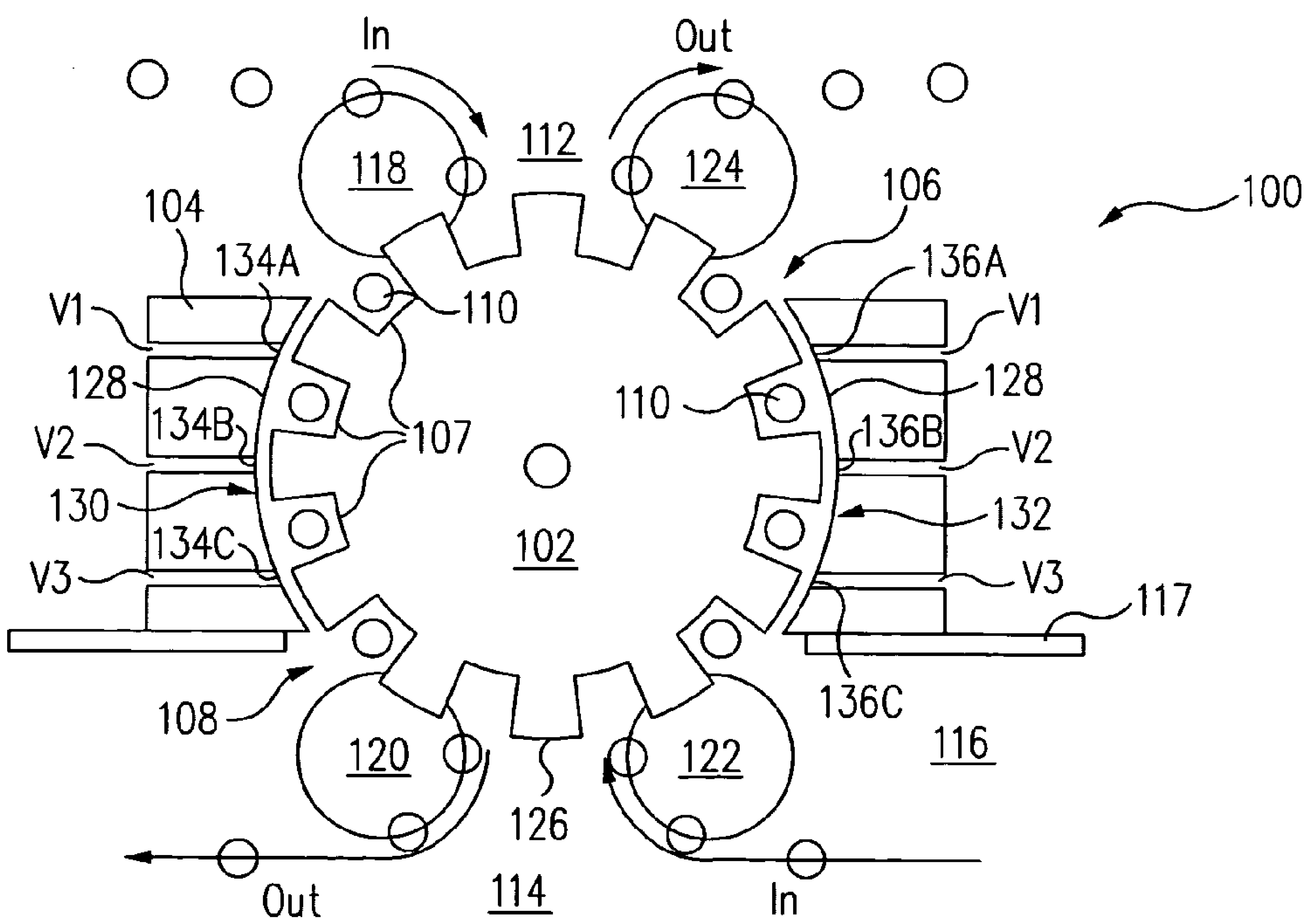
126
106
100

FIG. 1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V1
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V1
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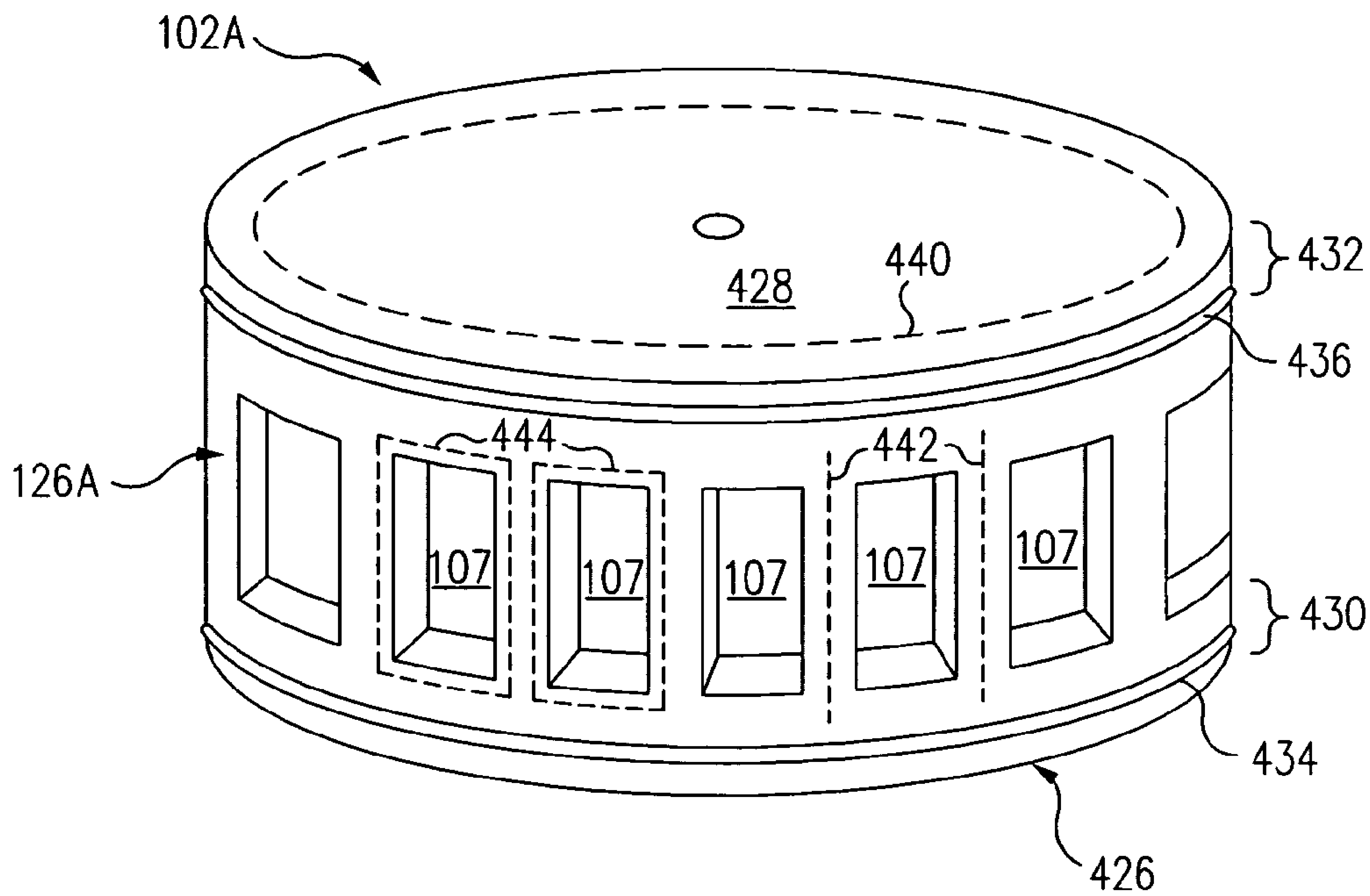
V2
V2
130
132
134C
102
V3
V3
117
136C
108
116
120
122
126
Out
114
In

FIG. 2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126A
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107
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107
107
430
434
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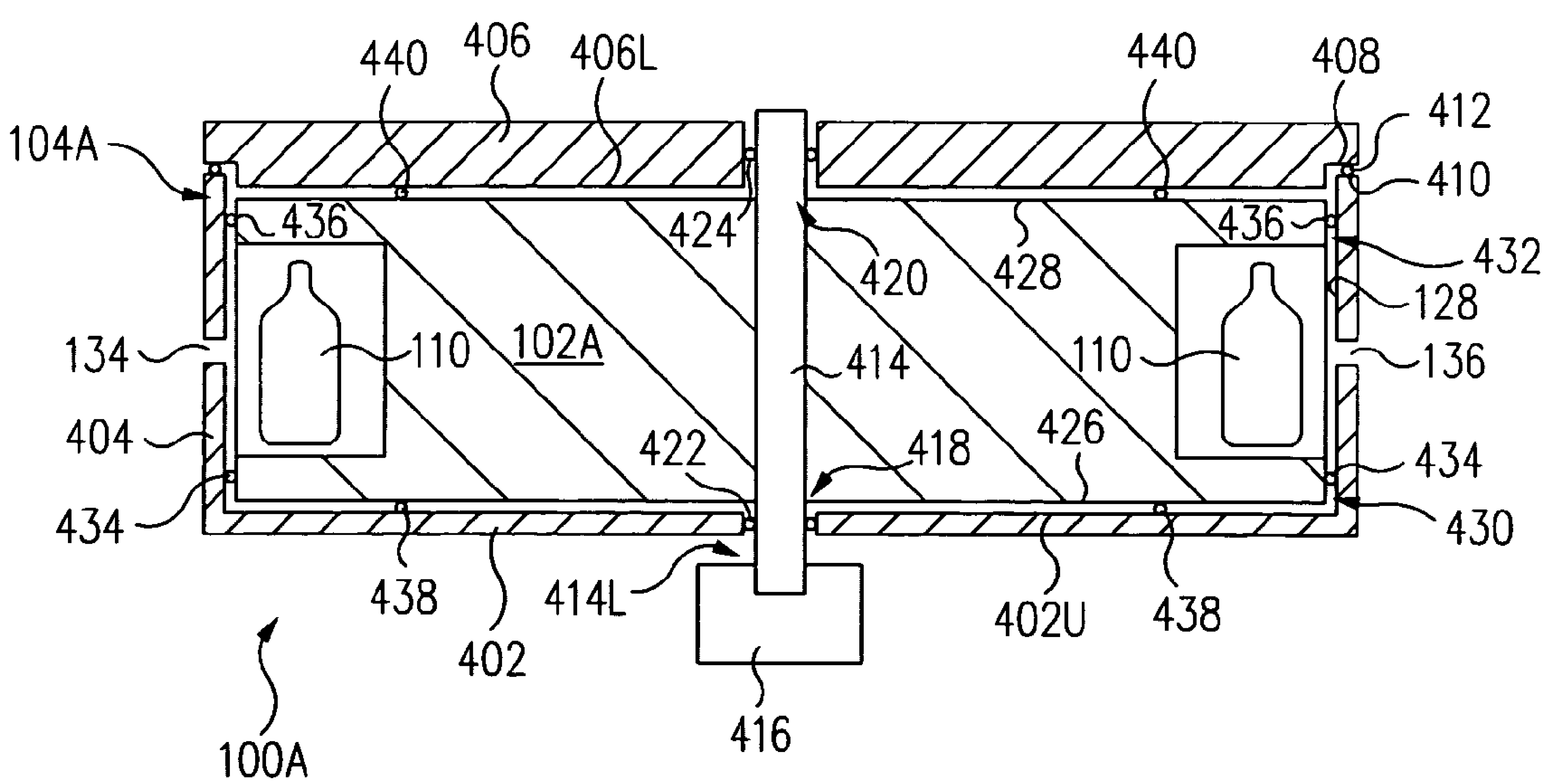
FIG. 3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110
136
404
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418
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434
434
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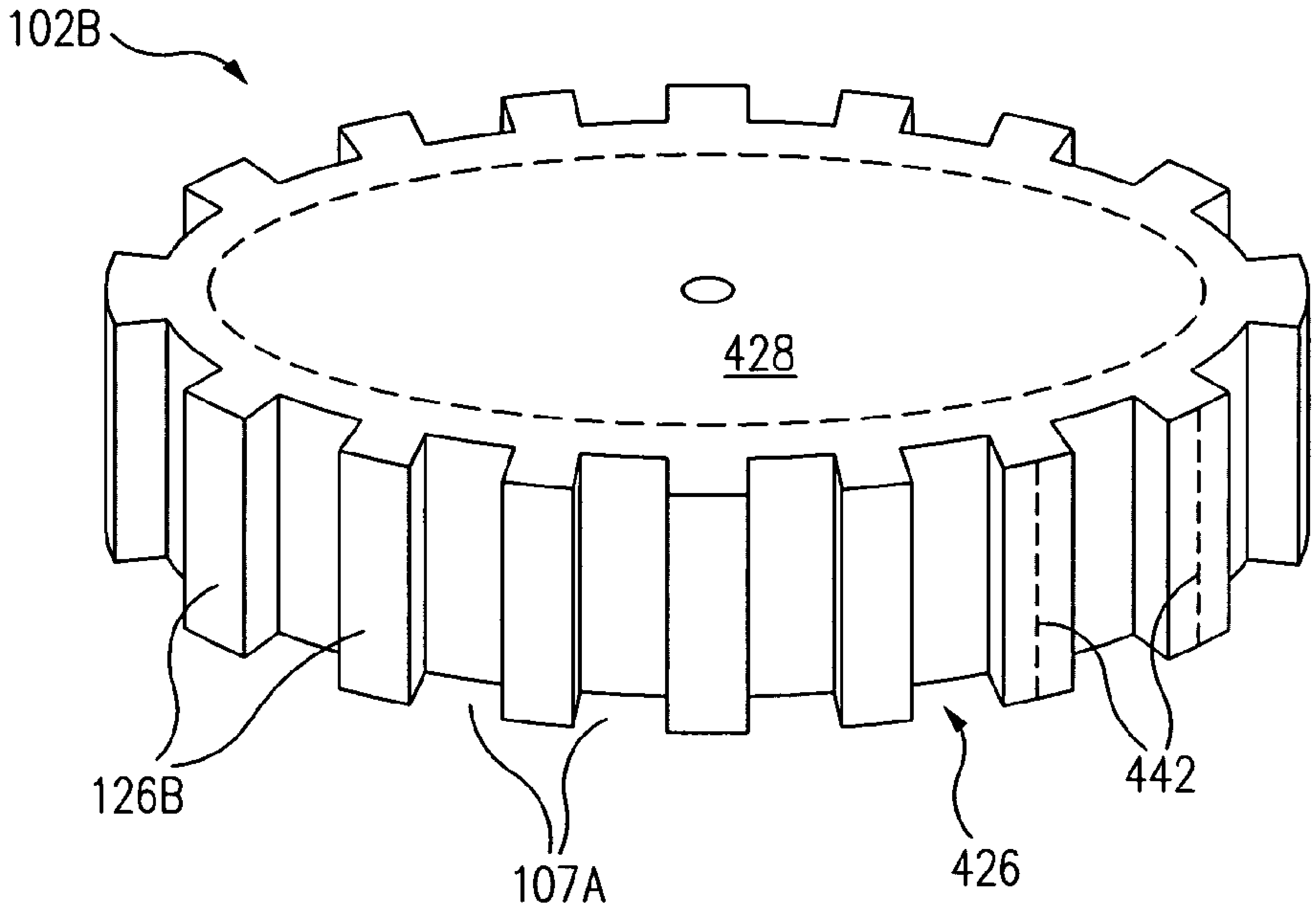
402
414L
402U
438
416
100A

FIG. 4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107A
426
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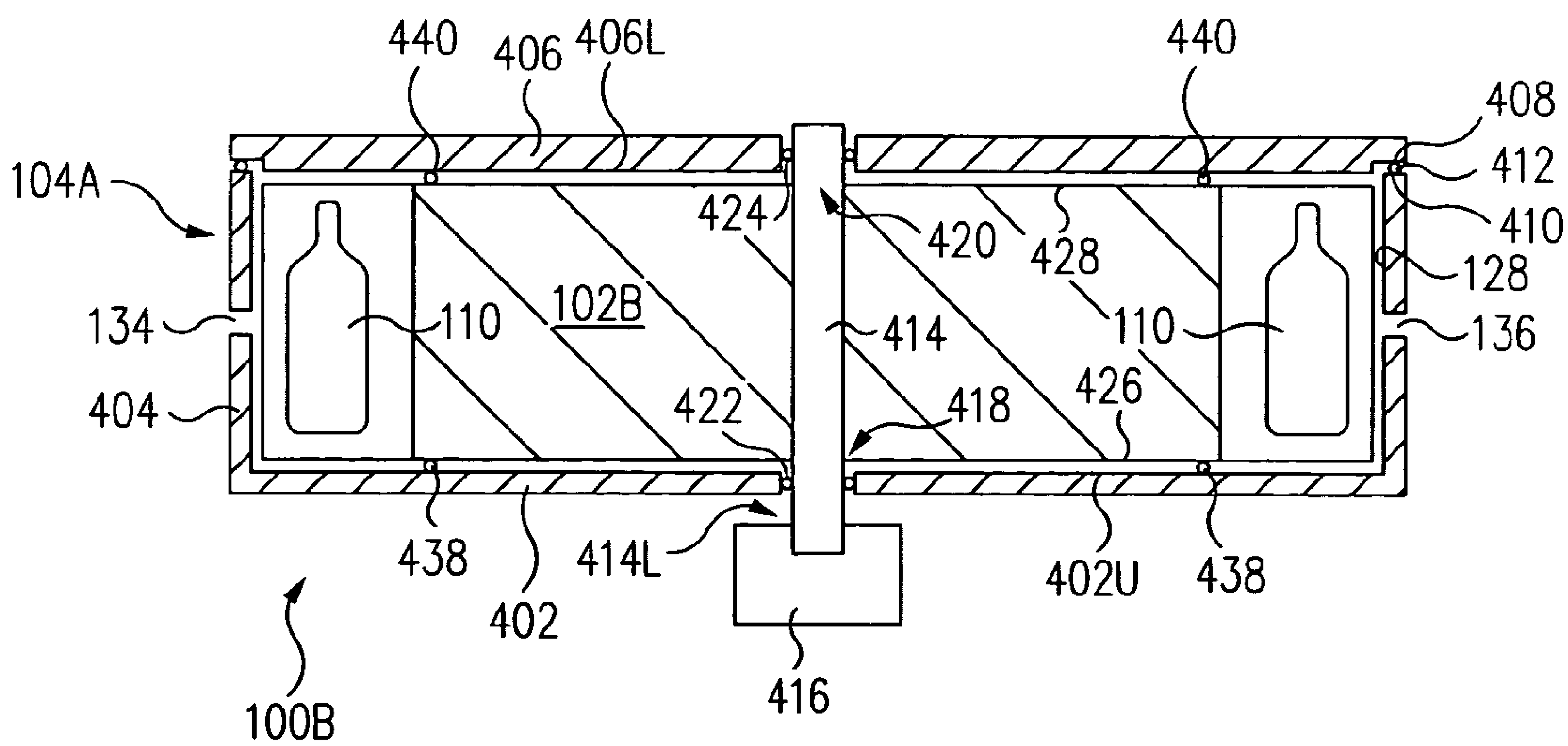
FIG. 5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402U
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100B

FIG. 6

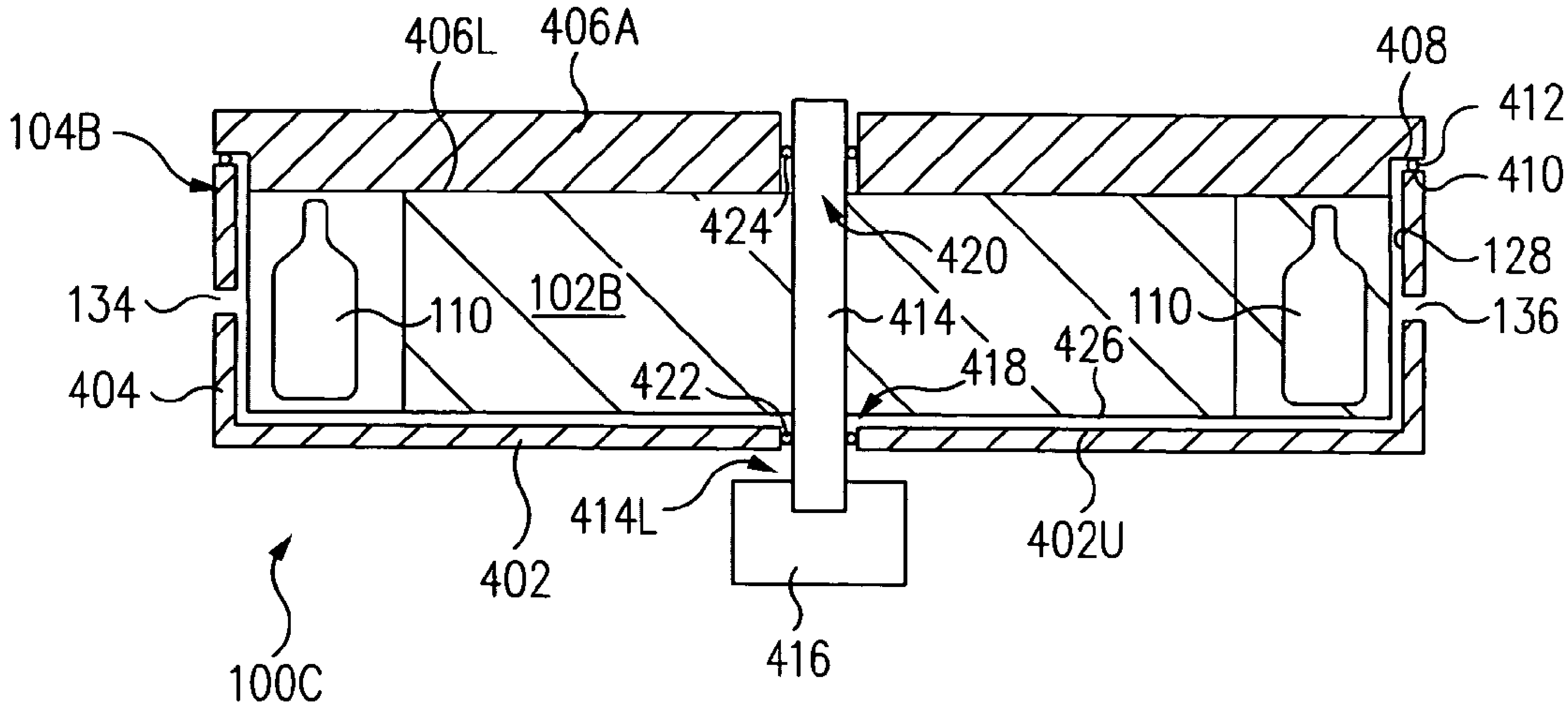
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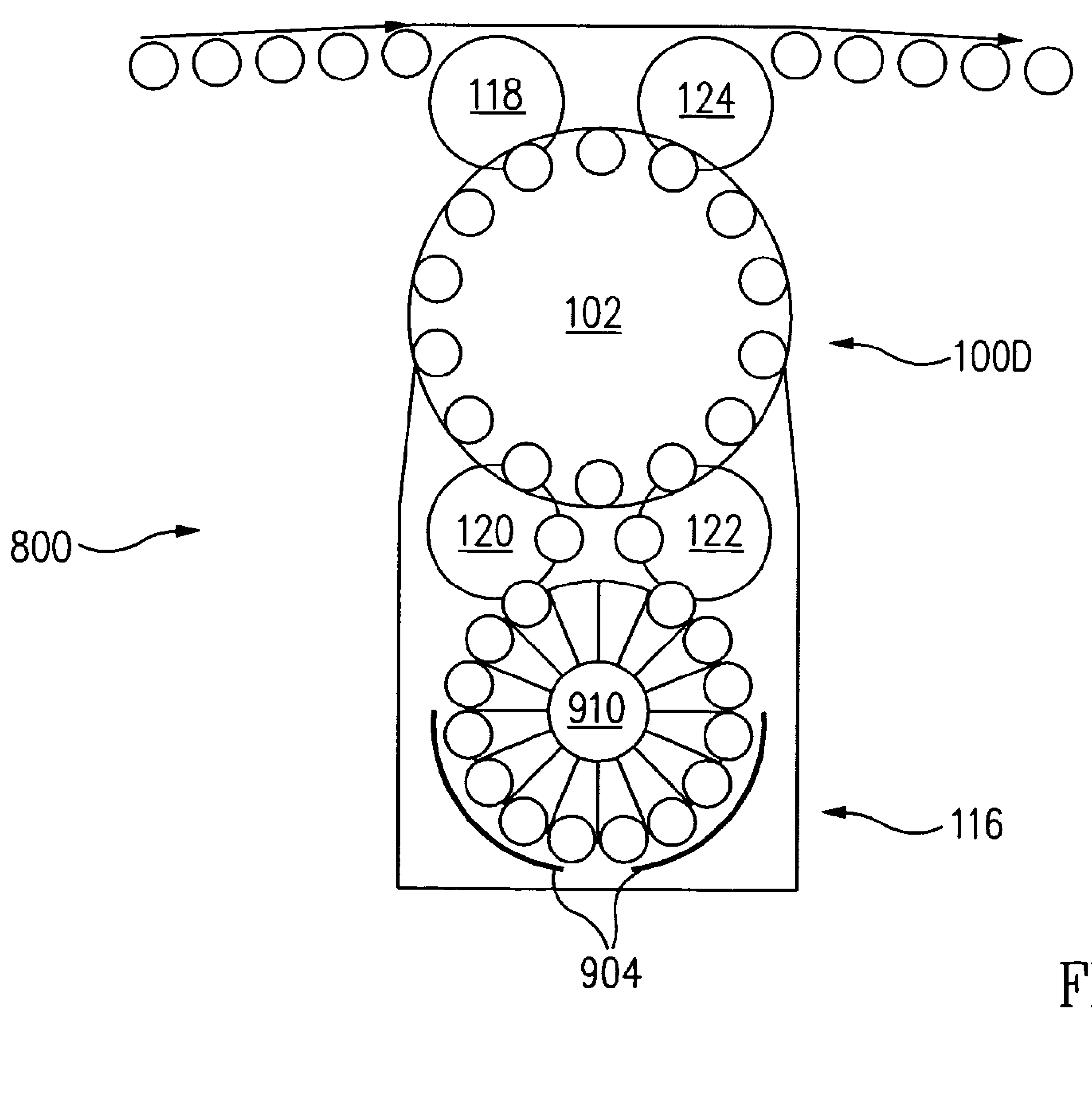
FIG. 7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122
910
116
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FIG. 8

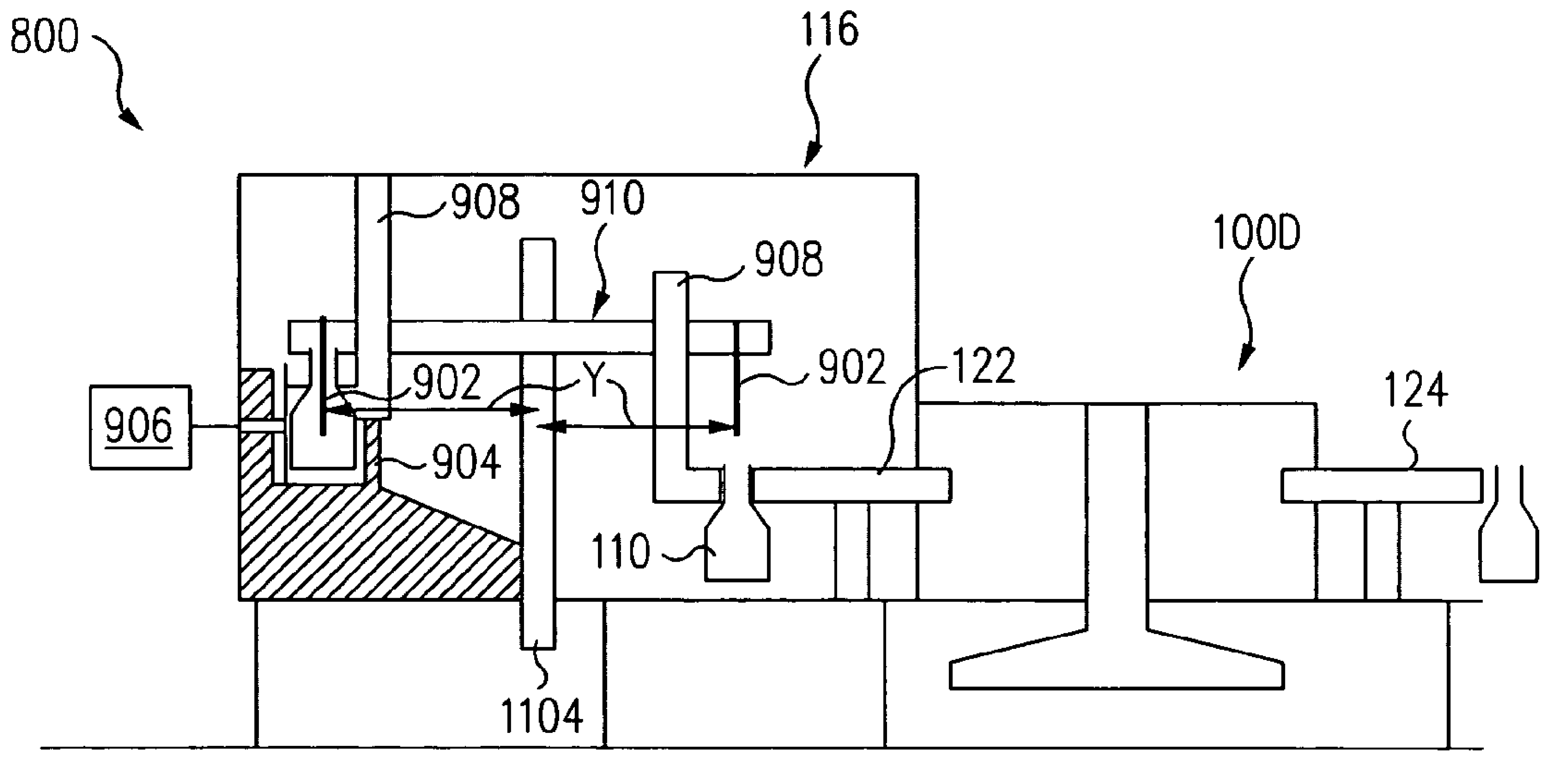
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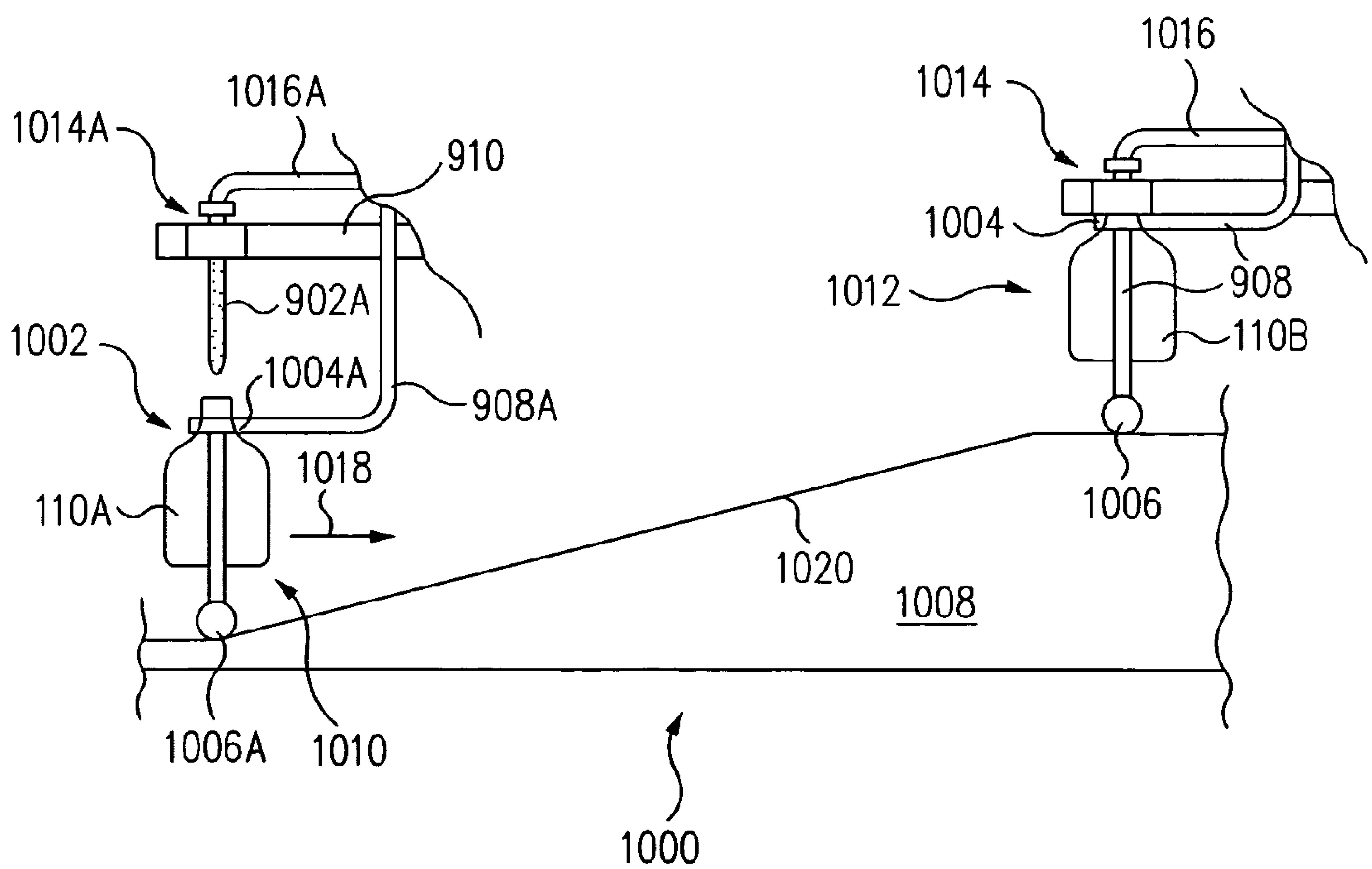
FIG. 9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1014
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910
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1018
110A
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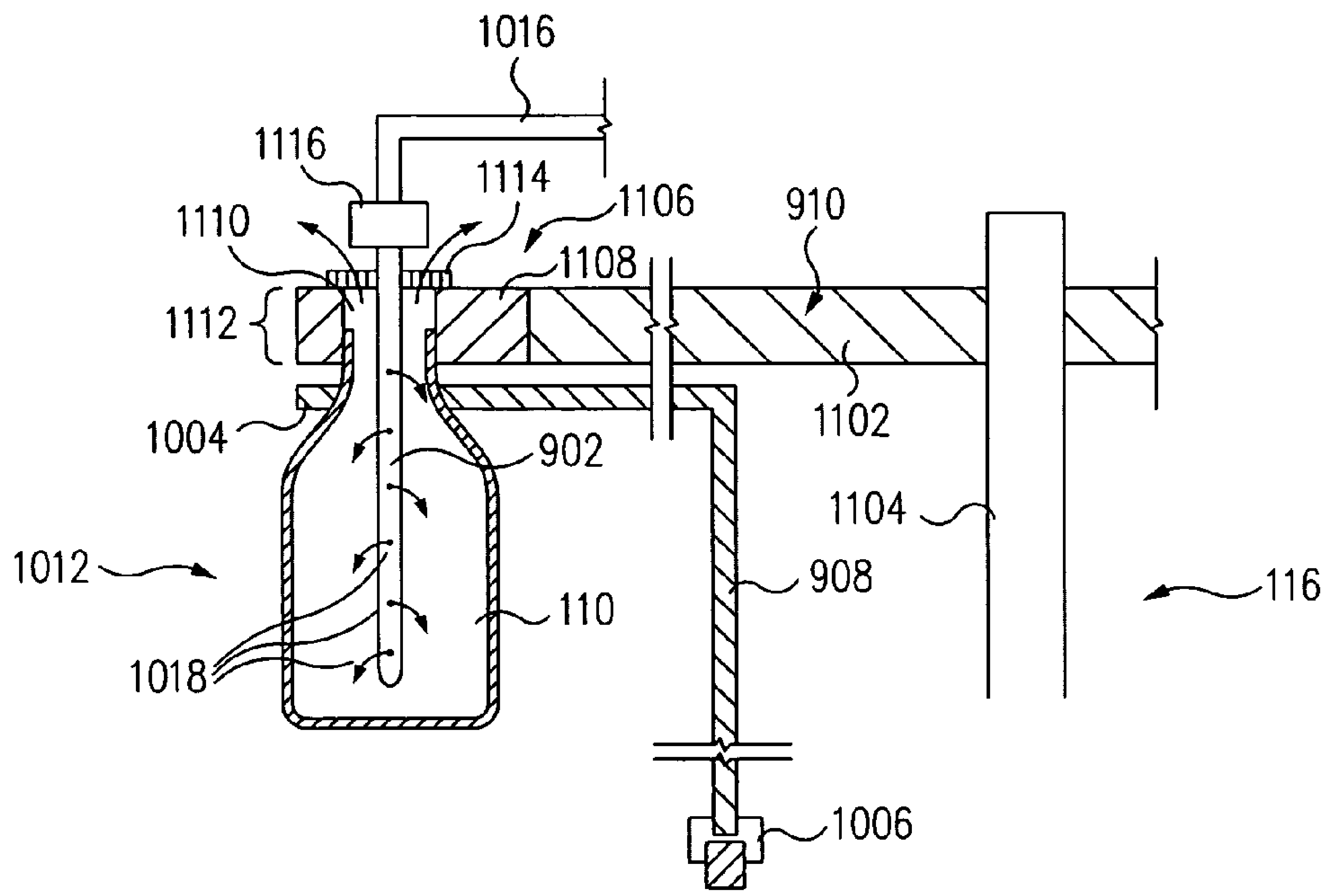
1020
1008
1006A
1010
1000

FIG. 10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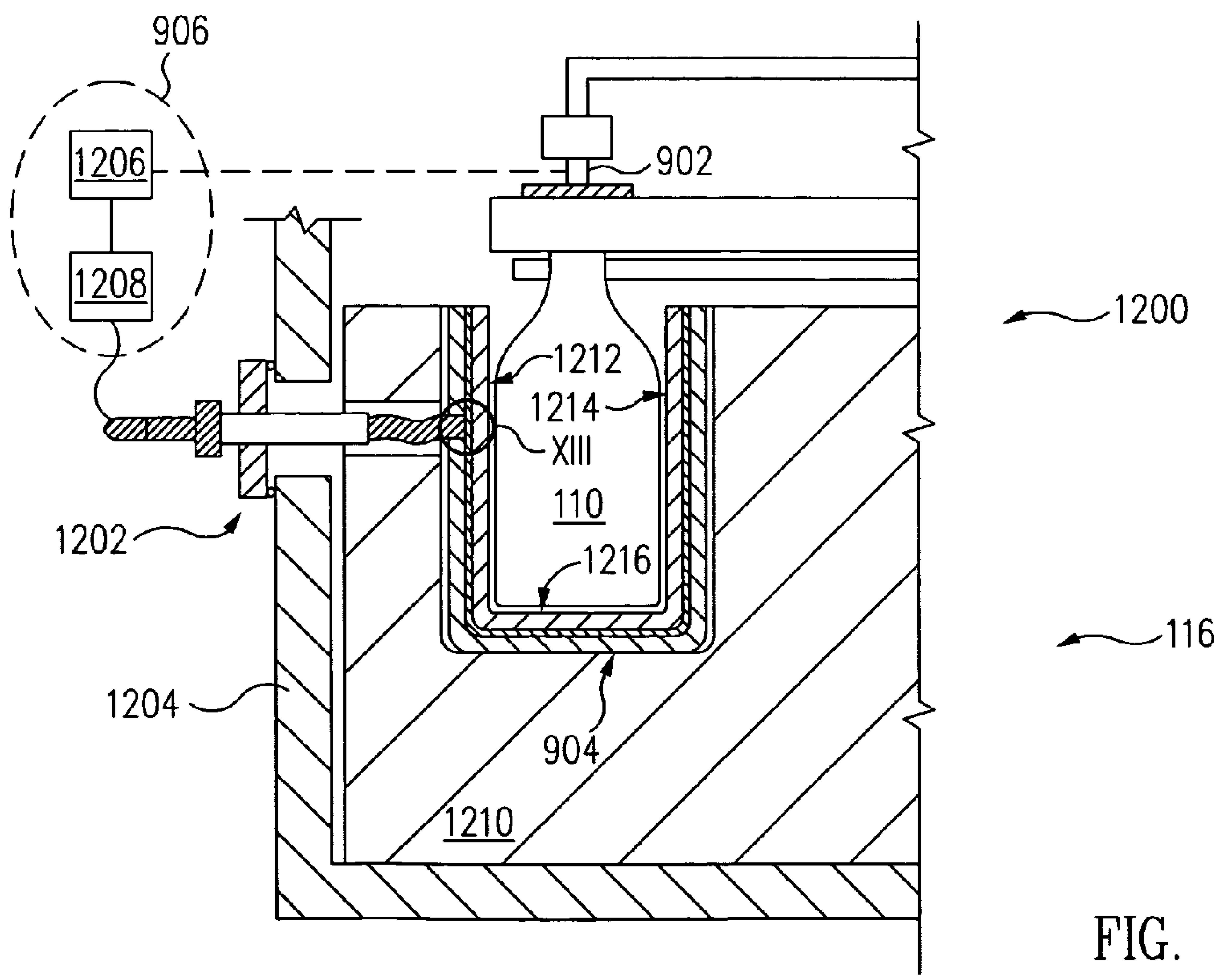
1018
1006

FIG. 11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1206
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XIII
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904
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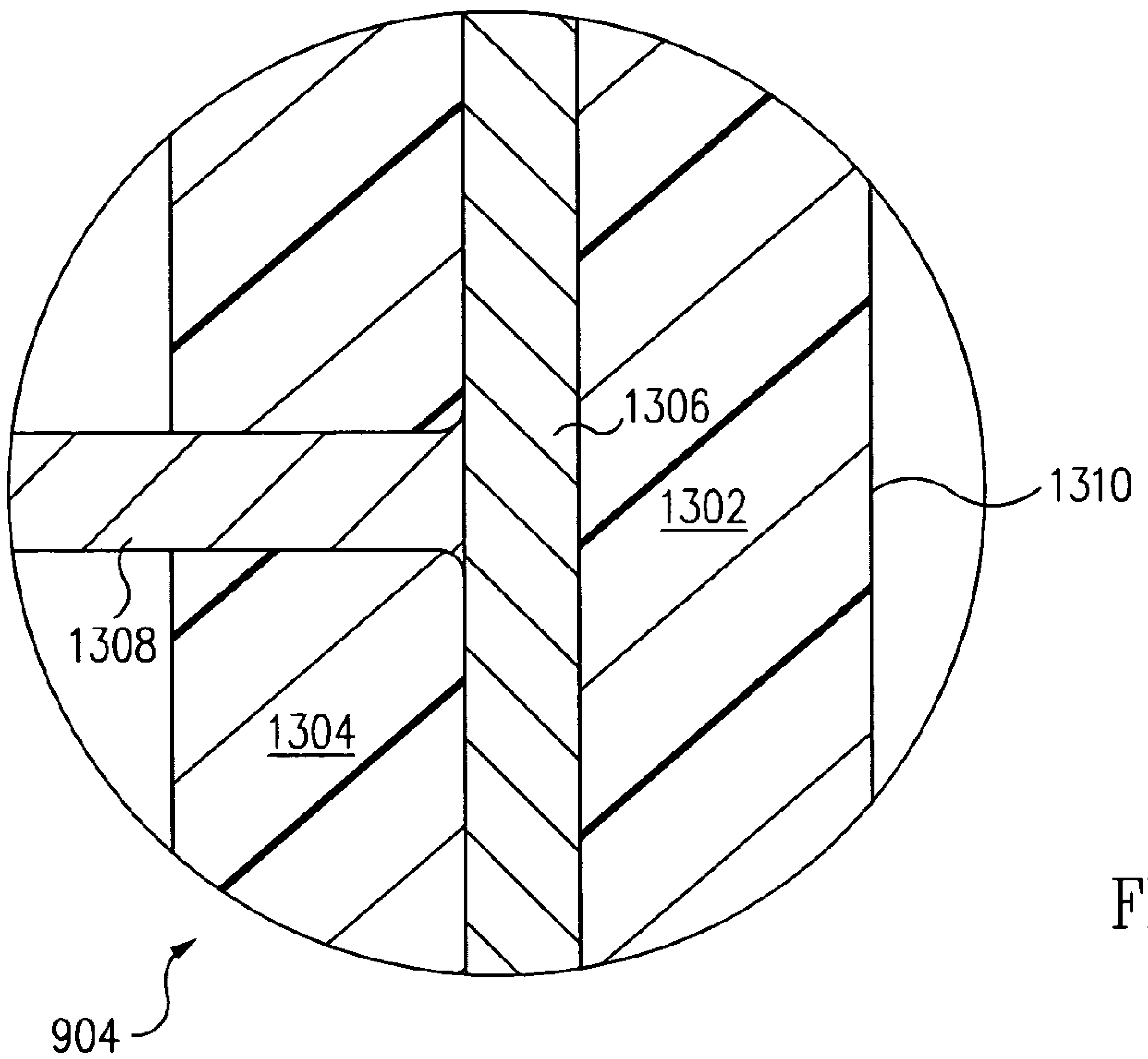
FIG. 12


1306
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1308
1304
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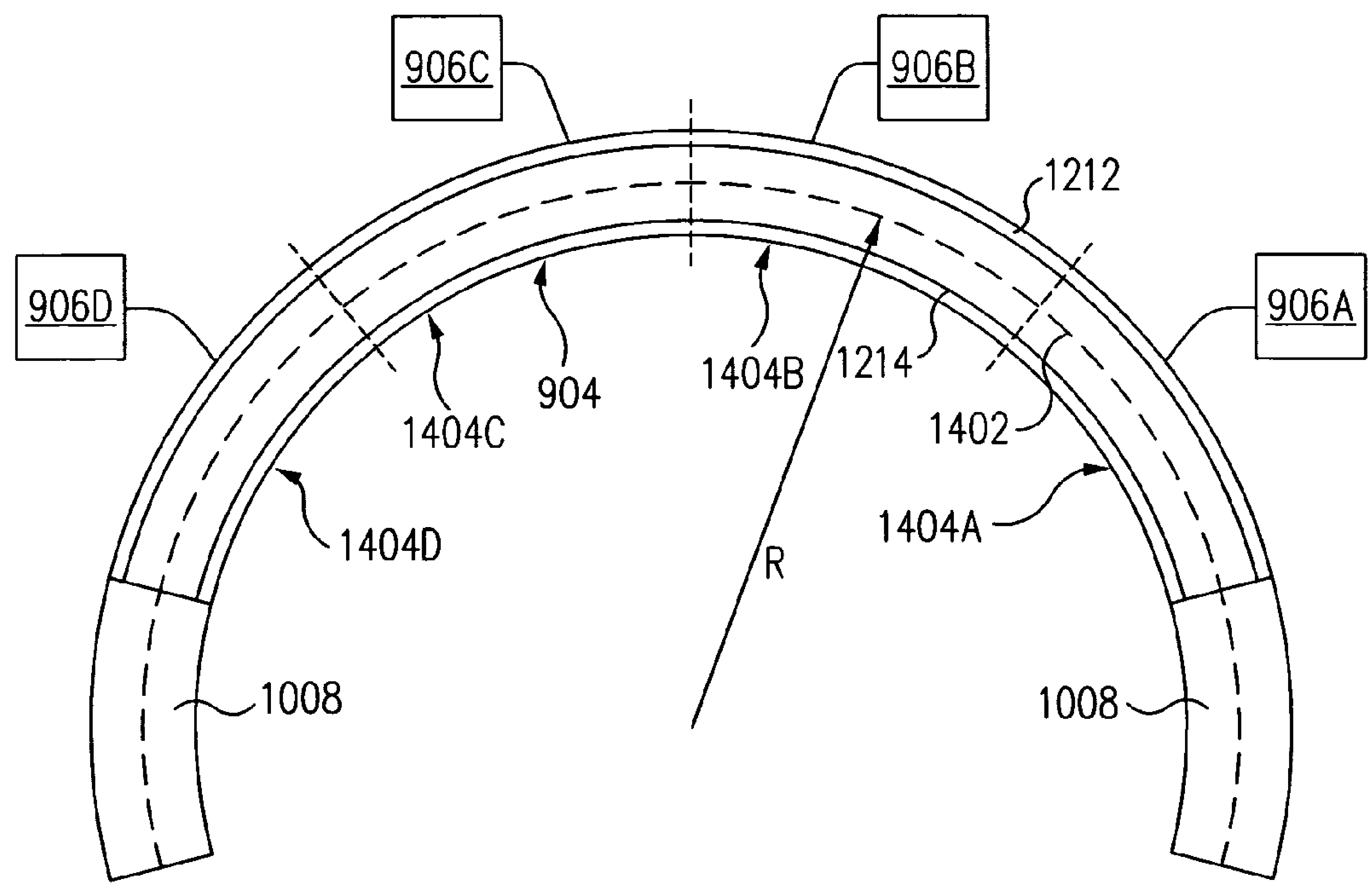
FIG. 13


906C
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906D
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1404C
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1404A
R
1008
1008

FIG. 14

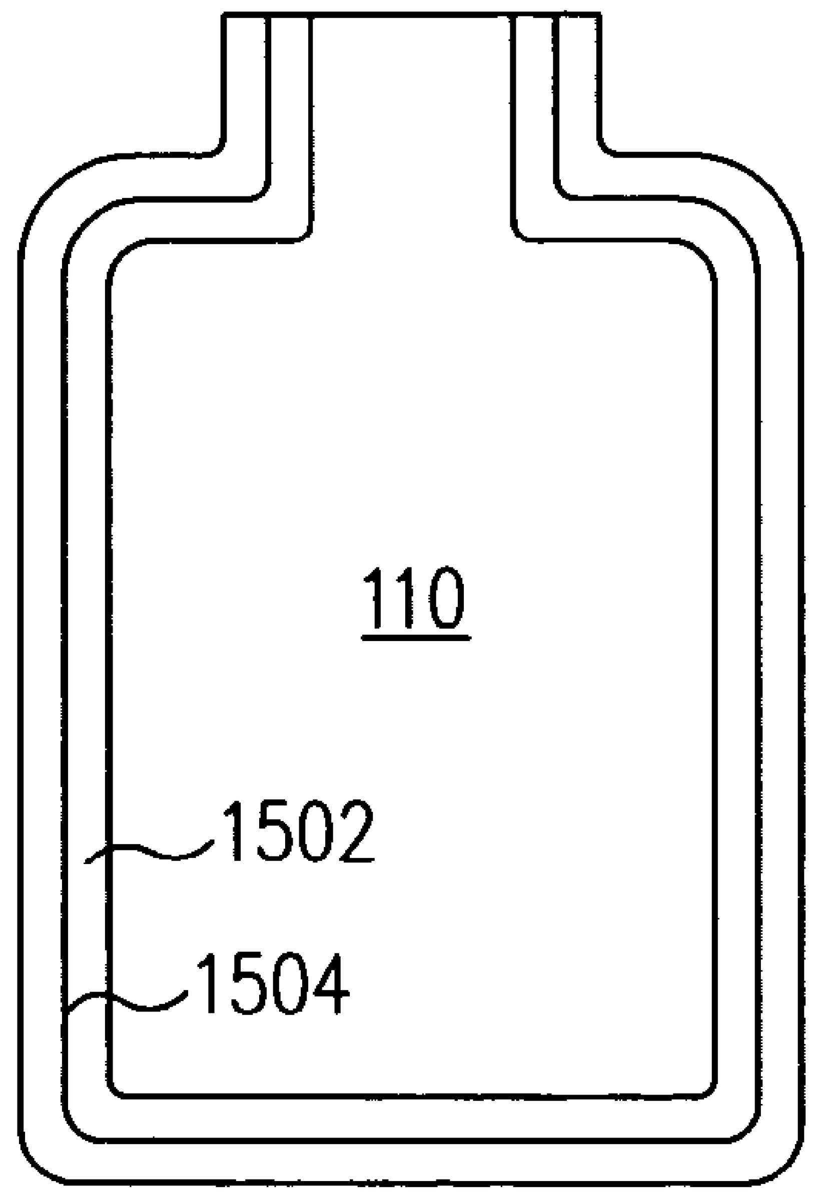
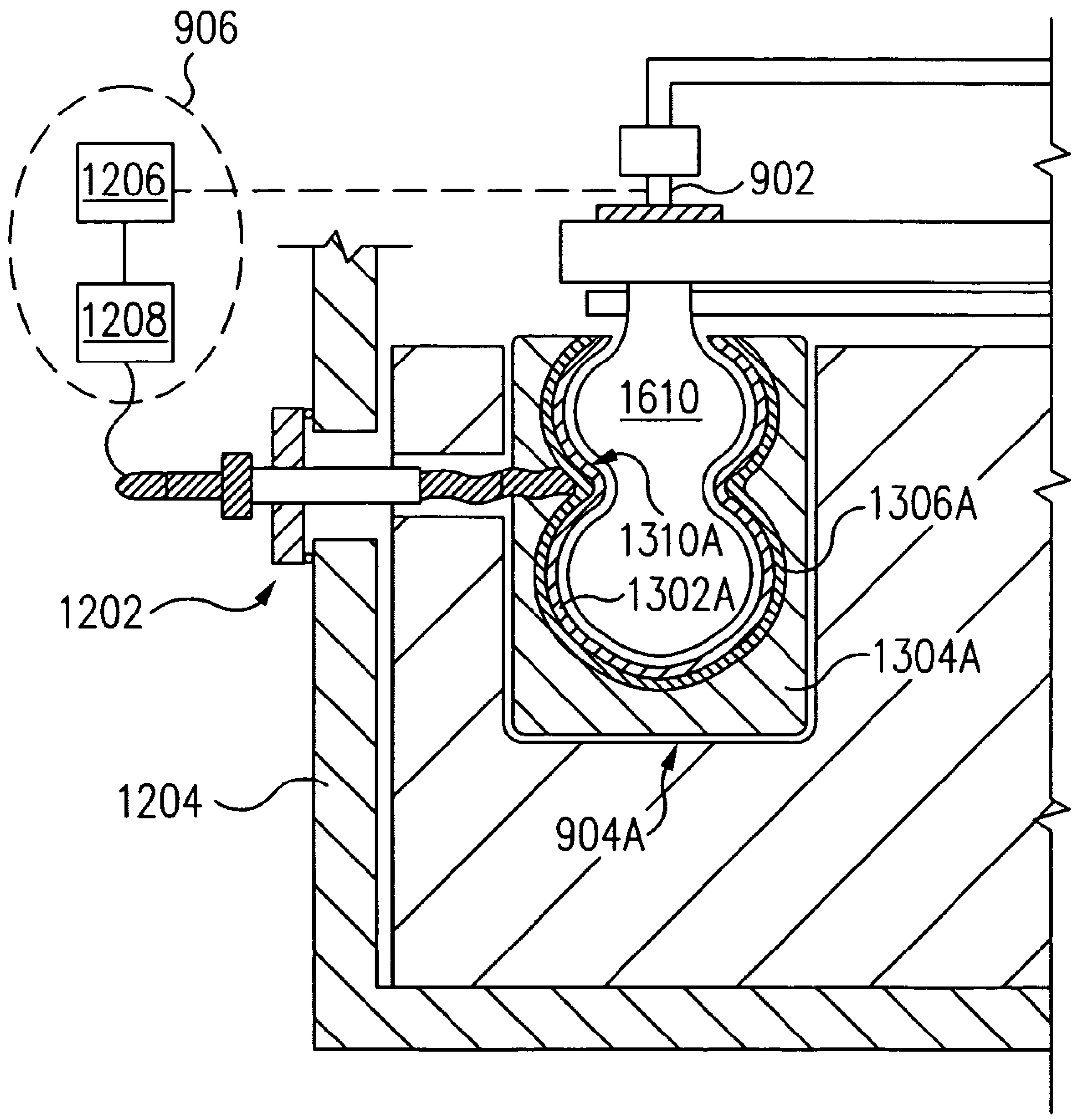

110
1502
1504

FIG. 15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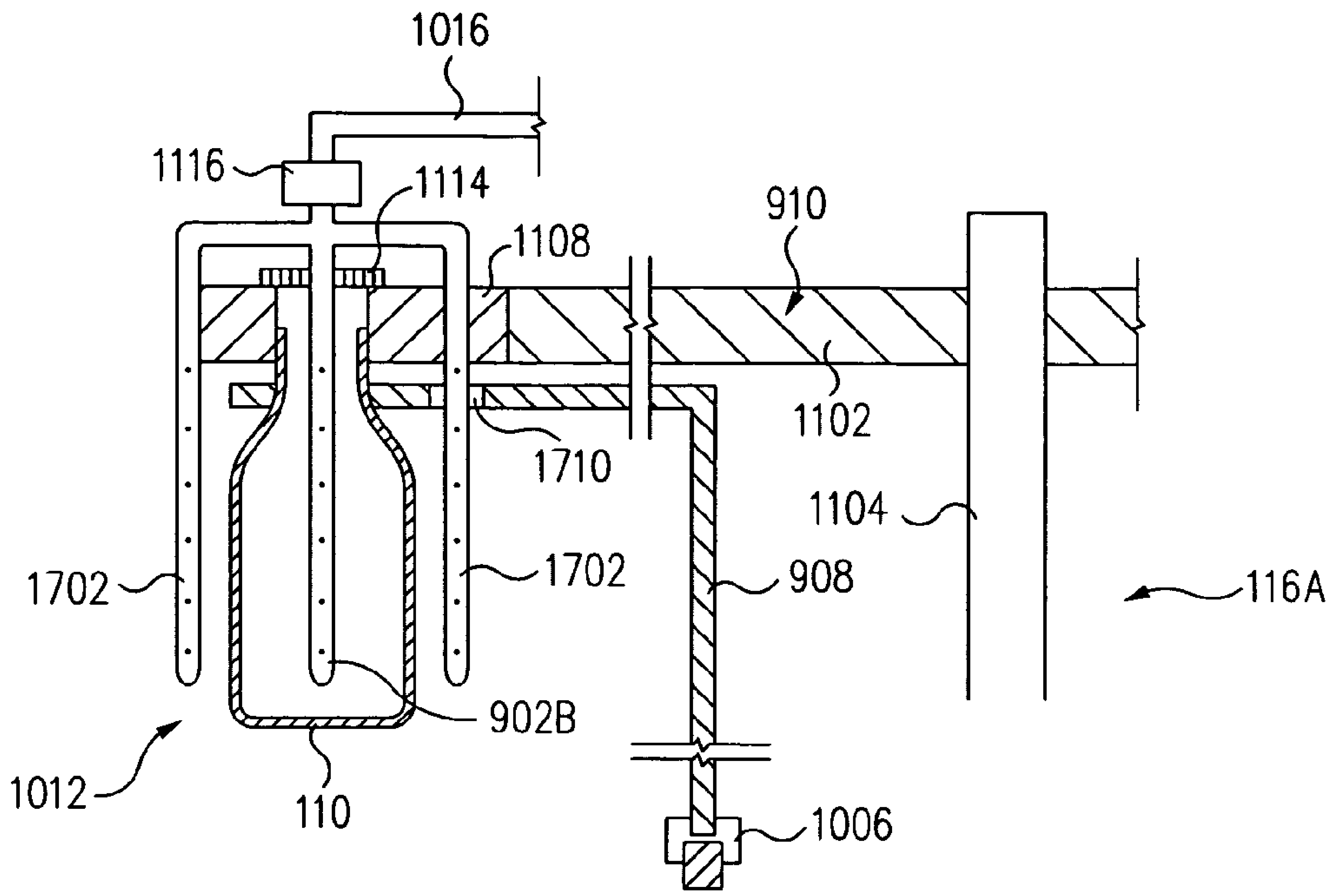
1304A
1202
1204
904A

FIG. 16


1016
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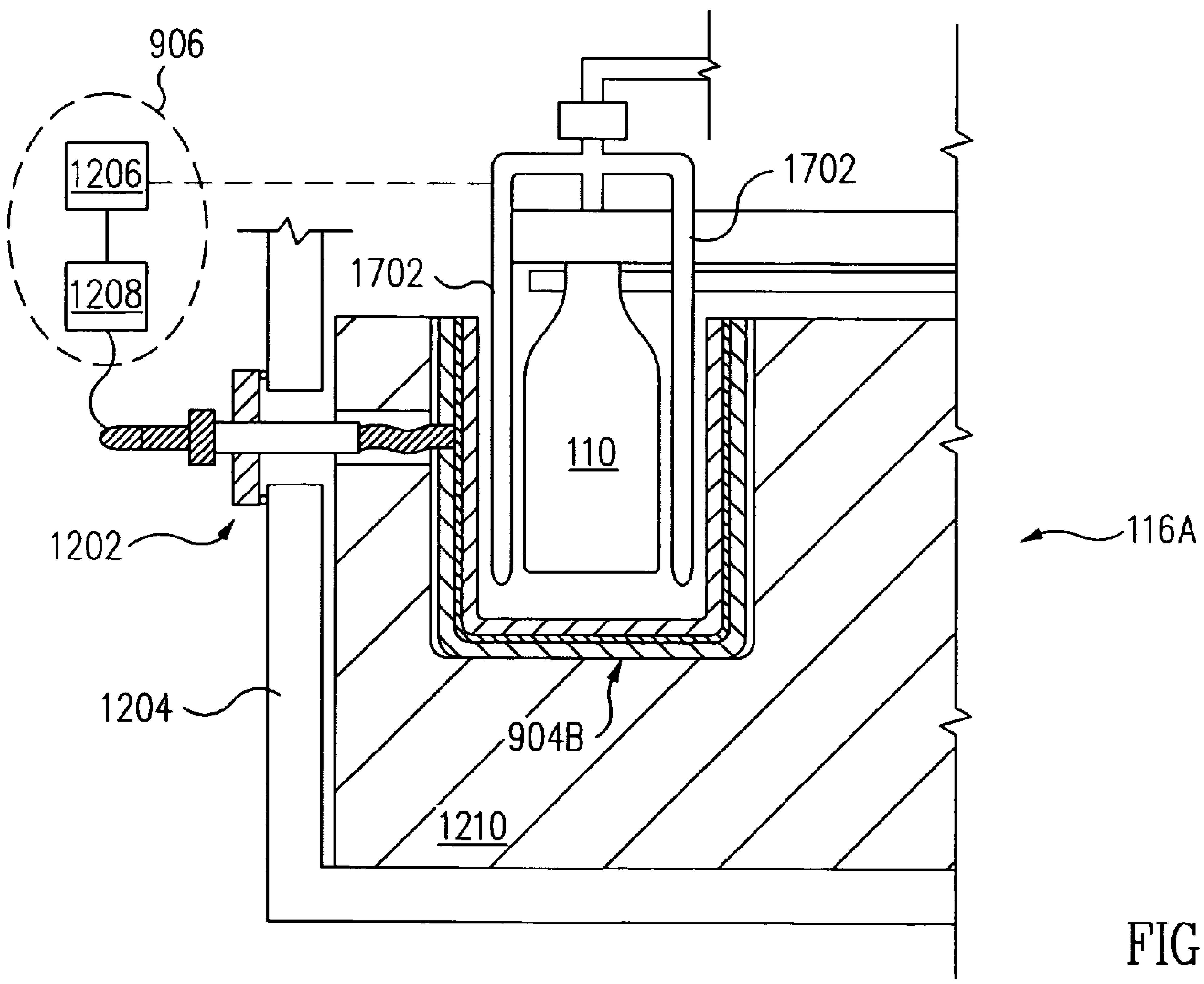
1108
910
1102
1710
1104
1702
1702
908
116A
902B
1012
110
1006

FIG. 17


906
1206
1208
1702
1702
110
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116A
1204
904B
1210

FIG. 18

CONTINUOUS SYSTEM FOR DEPOSITING FILMS ONTO PLASTIC BOTTLES AND METHOD

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Application No. 60/525,313, filed on Nov. 25, 2003, entitled "SYSTEM AND METHOD FOR DEPOSITING INORGANIC THIN FILMS ONTO THE INTERIOR OF PLASTIC BOTTLES", of John T. Felts, which is herein incorporated by reference in its entirety.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a system and method for depositing oxide and other inorganic materials onto the inside surface of 3 dimensional shapes, such as bottles, at high rates appropriate for production environments.

2. Description of the Related Art

One of the greatest challenges in the plastics packaging business has been the reduction of gas transfer through polymeric materials to either stop gases from ingressing into the packaged product, or to stop gases from egressing from the packaged product. There have been many approaches attempted including new resin formulations and multi-layers of polymeric materials, but each has had problems finding widespread acceptance due to either the cost, non-recyclability or the performance.

Traditionally, polyester terepthalate (PET) is the polymer of choice when gas barrier is needed in plastic packaging. In the three-dimensional (or rigid packaging area), PET is used in almost all applications where shelf-life and clarity are required.

Rigid packaging, sometimes called three-dimensional packaging, includes bottles, cans, cups and typically excludes the so-called flexible packaging. Examples of flexible packaging include pouches, and bags.

Although widely used in rigid packaging, PET is limited in its ability to provide gas barrier to both gas coming into the product (gas ingress) and escaping (gas egress). In the case of beer, a highly oxygen sensitive beverage, even the oxygen that is adsorbed in the wall of the PET bottle can significantly alter the taste and shelf-life of the beer. For carbonated soft drinks (CSD), on the other hand, the barrier must stop carbon dioxide from escaping out of the beverage and there are little to no concerns about the ingress of gases.

There are three conventional approaches to providing barriers in PET bottles; multi-layers, mono-layers, and surface coatings. The first approach is to provide a multi-layer structure that sandwiches the PET structural layers around a core, a single layer or multiple layers, containing higher-priced barrier materials.

This first approach has been utilized by incorporating ethylene vinyl alcohol (EVOH) as the core. EVOH provides excellent oxygen barrier properties, however, EVOH is highly moisture sensitive and the barrier properties deteriorate with exposure to water. Other materials such as nylon have also been investigated but have had issues with recyclability and cost.

There are several new barrier materials including nylon-based nanocomposites and "passive-active" barrier systems. The passive-active barrier systems include dual-acting formulations of a passive barrier material and an active oxygen scavenger that blocks oxygen by adsorbing it chemically.

Both of these materials have been successfully integrated into multi-layer structures, however, none have been demonstrated to be recyclable, and due to the high cost of the barrier materials, the overall cost of the package is outside of acceptable limits.

The "ideal" route to providing barriers in PET bottles (and the second conventional approach) is to use a monolayer that either incorporates a barrier material (mixed with PET to reduce cost) or is formed of a single polymer. There are, however, few practical monolayer materials under development. Further, there is still the significant issue of recycle of the monolayer, since the current recycle streams for polymers are set-up to handle only polyolefins (which offer no barrier to oxygen) and PET. Any composite material (incorporating PET) or other polymer would potentially contaminate the current recycle streams.

The third conventional approach to providing barriers in PET bottles is surface coating technologies where a thin layer is applied to either the exterior or interior surface of the PET bottle. If a polymer is used, the same issues discussed above are present for recycle. Thus, the current focus of this area is the deposition of thin film coatings of silicon oxide or a carbon based material.

Thin films are defined as coatings that are measured on the angstrom (Å) level. Typically, the thin film coatings discussed as barrier materials range in thickness from 100-5000 Å in total thickness.

There are two approaches currently being developed for the deposition of the thin film coatings, physical vapor deposition and chemical vapor deposition. For examples of physical vapor deposition techniques, see U.S. Pat. Nos. 6,279,505, 6,276,296, 6,251,233, 6,223,683, 6,520,318.

Physical vapor deposition techniques have not been successful due to the application of the thin film onto the exterior surface of the bottle and the inherent damage that the thin film incurs during subsequent processing such as during filling, labeling, capping and transportation. To prevent this damage to the thin film, a second additional coating that protects the thin film from damage was sprayed onto the thin film. This additional coating adds processing time and increases the cost of the barrier technology and final package.

The second approach currently being developed for the deposition of the thin film coatings is by chemical vapor deposition utilizing plasma enhanced chemical vapor deposition (PECVD), where the coating is derived from gases that are decomposed within the bottle by a plasma. The plasma, an electrically ionized gas, is created by coupling power into the gas mixture (held at a pressure significantly lower than atmospheric pressure) through an electric field. The PECVD approach can be broken down further into carbon and silicon based chemistries. For examples of carbon based and silicon based coatings see U.S. Pat. No. 6,294,226 and U.S. Pat. Nos. 6,565,791, 6,117,243, 5,972,436, 5,900,285, 6,390,020, 6,055,929, 5,993,598, 5,900,284, 6,180,191 and 6,112,695.

In the application of the surface coating technologies, one of the key performance factors is the speed at which the bottles are coated. The coating speed should be near the rate at which bottles are produced from blow molding, which currently averages around 20,000 bottles per hour (bph), but can be as high as 60,000 bph.

If the coating speed cannot achieve at least 20,000 bph and be extendable to at least 40,000 bph, there will be significant limitations in terms of the utilization efficiency of the apparatus. With current trends, a desirable technology should be extendable to 40,000 bph. As will be discussed below, one significant limitation of existing surface coating applications based on thin film materials (carbon or silicon based), is that no commercial equipment can be extended beyond 10,000 bph.

To date, each bottle that is coated on the interior with a thin film coating has been treated as a separate entity. In this approach, the interior of each bottle and the surrounding environment are evacuated (with a vacuum pump) to process pressures, then gases are injected into the bottle and a plasma is ignited. The plasma, in contact with the interior of the plastic bottle, results in the thin film coating.

Once the coating process is completed, the bottle is evacuated a second time, and then vented to atmospheric pressure. Since each bottle is treated independent of other bottles, pumping, gas and power systems must be duplicated for each individual bottle reactor. This results in duplication of costs, but more importantly, results in significant increases in process cycle time (defined as the time from when a bottle enters the machine until it exits with a thin film coating on the inside). In addition, the only means to increase the number of bottles processed through the machine (assuming that the coating time is constant), is to increase the number of coating cells and associated hardware. This results in significant increases in the size and cost of the equipment.

SUMMARY OF THE INVENTION

In accordance with one embodiment of the present invention, a bottle processing apparatus includes a rotary bottle vacuum transfer system and a bottle coating system. The rotary bottle vacuum transfer system takes bottles from atmospheric pressure, sometimes called ambient pressure, and transfers the bottles to the bottle coating system at a sub-atmospheric pressure in a continuous assembly line fashion. In the bottle coating system, a thin film coating having barrier properties is formed on at least one surface of the bottles in a continuous assembly line fashion. After formation of the thin film coating, the rotary bottle vacuum transfer system returns the bottles from the sub-atmospheric pressure region of the bottle coating system back to atmospheric pressure.

The bottles are coated using the bottle processing apparatus in a continuous assembly line fashion at a high rate appropriate for commercial production environments. In one embodiment, the bottles are coated at a rate of at least 20,000 bph, e.g., 40,000 bph, thus maximizing the utilization efficiency of the bottle processing apparatus.

Further, the bottles are treated continuously in an assembly line fashion using common pumping, gas and power systems. This avoids duplication of costs and results in a significant decrease in process cycle time.

In one embodiment, the bottle processing apparatus is capable of depositing silicon dioxide thin films with gas barrier improvements (over the base polymer) of at least 2× at rates exceeding 10,000 bottles per hour.

In another embodiment, the bottle processing apparatus is capable of producing silicon dioxide interior coated bottles at rates exceeding 20,000 bottles per hour with gas barrier improvements of 2-30×.

These and other features of the present invention will be more readily apparent from the detailed description set forth below taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a perspective view of a rotary bottle vacuum transfer system in accordance with one embodiment of the present invention;

FIG. **2** is a cross-sectional view of the rotary bottle vacuum transfer system of FIG. **1** along the line II-II in accordance with one embodiment of the present invention;

FIG. **3** is a perspective view of a rotary bottle transfer wheel in accordance with one embodiment of the present invention;

FIG. **4** is a cross-sectional view of a rotary bottle vacuum transfer system incorporating the rotary bottle transfer wheel of FIG. **3** in accordance with one embodiment of the present invention;

FIG. **5** is a perspective view of a rotary bottle transfer wheel in accordance with another embodiment of the present invention;

FIG. **6** is a cross-sectional view of a rotary bottle vacuum transfer system incorporating the rotary bottle transfer wheel of FIG. **5** in accordance with one embodiment of the present invention;

FIG. **7** is a cross-sectional view of a rotary bottle vacuum transfer system incorporating the rotary bottle transfer wheel of FIG. **5** in accordance with another embodiment of the present invention;

FIGS. **8** and **9** are top and side schematic views of a bottle processing apparatus in accordance with one embodiment of the present invention;

FIG. **10** is a side schematic view of a bottle lift mechanism in accordance with one embodiment of the present invention;

FIG. **11** is a cross-sectional view of a bottle in an elevated position around a gas inlet in accordance with one embodiment of the present invention;

FIG. **12** is a cross-sectional view of a bottle within a U-channel in accordance with one embodiment of the present invention;

FIG. **13** is an enlarged cross-sectional view of the region XIII of the U-channel of FIG. **12**;

FIG. **14** is a schematic top view of the U-channel of FIG. **12** in accordance with one embodiment of the present invention;

FIG. **15** is a cross-sectional view of a bottle having a barrier coating deposited on the interior surface of the bottle in accordance with one embodiment of the present invention;

FIG. **16** is a cross-sectional view of a hoop-skirt bottle within a U-channel in accordance with another embodiment of the present invention;

FIG. **17** is a cross-sectional view of a bottle in an elevated position around a gas inlet in accordance with yet another embodiment of the present invention; and

FIG. **18** is a cross-sectional view of the bottle of FIG. **17** within a U-channel in accordance with one embodiment of the present invention.

In the following description, the same or similar elements are labeled with the same or similar reference numbers.

DETAILED DESCRIPTION

FIG. **1** is a perspective view of a rotary bottle vacuum transfer system **100** in accordance with one embodiment of the present invention. FIG. **2** is a cross-sectional view of rotary bottle vacuum transfer system **100** of FIG. **1** along the line II-II in accordance with one embodiment of the present invention.

Referring now to FIGS. **1** and **2** together, rotary bottle vacuum transfer system **100**, sometimes called a rotary delivery mechanism, includes a rotary bottle transfer wheel **102** within a chamber **104**. Chamber **104** includes an atmospheric port **106** and a vacuum port **108**.

Bottles **110**, e.g., PET bottles, are continuously transferred from an exterior region **112** at atmospheric pressure into rotary bottle vacuum transfer system **100** through atmospheric port **106**. Bottles **110** are continuously brought from atmospheric pressure to a sub-atmospheric pressure, e.g., in the range of 1-1000 mTorr (10-100 mTorr in one embodiment), within bottle vacuum transfer system **100**. Bottles **110** are continuously transferred at a sub-atmospheric pressure from bottle vacuum transfer system **100** through vacuum port **108** to an interior region **114** also at a sub-atmospheric pressure.

In one embodiment, interior region **114** is a sub-atmospheric pressure region located within a bottle coating system **116** mounted to rotary bottle vacuum transfer system **100**. For example, rotary bottle vacuum transfer system **100** is mounted to a chamber wall **117** of bottle coating system **116**, sometimes called a vacuum chamber. In accordance with one embodiment, an inorganic thin film is continuously formed on the interior and/or exterior surfaces of bottles **110** within the bottle coating system as discussed further below.

After processing, bottles **110** are continuously transferred from interior region **114** at the sub-atmospheric pressure into rotary bottle vacuum transfer system **100** through vacuum port **108**. Bottles **110** are continuously brought from the sub-atmospheric pressure to atmospheric pressure within rotary bottle vacuum transfer system **100**. Bottles **110** are continuously transferred at atmospheric pressure from rotary bottle vacuum transfer system **100** through atmospheric port **106** to exterior region **112**, which is at atmospheric pressure.

As set forth above, bottles **110** are continuously transferred to and from bottle coating system **116** in a continuous assembly line fashion. To facilitate this continuous transfer, rotary bottle transfer wheel **102** includes a plurality of bottle cutouts **107** into which bottles **110** are inserted and removed. A continuous assembly line fashion in accordance with one embodiment is an arrangement where bottles **110** are in continuous motion and move along a common path.

For example, bottles **110** are inserted through atmospheric port **106** and into bottle cutouts **107** by a first transfer wheel **118**. Bottles **110** are removed through vacuum port **108** and from bottle cutouts **107** by a second transfer wheel **120**. Similarly, bottles **110** are inserted through vacuum port **108** and into bottle cutouts **107** by a third transfer wheel **122**. Bottles **110** are removed through atmospheric port **106** and from bottle cutouts **107** by a fourth transfer wheel **124**. Transfer wheels such as transfer wheels **118**, **120**, **122** and **124** are well known to those of skill in the art and so are not discussed in detailed to avoid detracting from the principles of the invention. Further, bottles **110** can either be held in-place (for example by the neck of the bottle) through rotary bottle vacuum transfer system **100**, or conveyed by an appropriate means.

In accordance with this embodiment, rotary bottle transfer wheel **102** is cylindrically shaped. More particularly, rotary bottle transfer wheel **102** includes an exterior cylindrical surface **126**, in which bottle cutouts **107** are formed. Further, chamber **104** includes an interior cylindrical surface **128** directly adjacent and corresponding to exterior cylindrical surface **126** of rotary bottle transfer wheel **102**.

As used herein, a cylindrical surface is a surface lying within the curved exterior surface of a circular cylinder. For example, referring to FIG. **2**, interior cylindrical surface **128** of chamber **104** includes a first pressure reduction section **130** and a second pressure increasing section **132**, pressure reduction section **130** and pressure increasing section **132** both lying within the curved exterior surface of a common cylinder. Pressure reduction section **130** and pressure increasing section **132** are sometimes called curved interior chamber walls.

Interior cylindrical surface **128** and, more particularly, pressure reduction section **130** and pressure increasing section **132** include at least one vacuum port, e.g., an aperture or apertures. In accordance with this embodiment, pressure reduction section **130** includes three vacuum ports **134**A, **134**B, **134**C, collectively vacuum ports **134**. Similarly, pressure increasing section **132** includes three vacuum ports **136**A, **136**B, **136**C, collectively vacuum ports **136**.

Vacuum ports **134** and **136** are coupled to a source of vacuum, for example, to a single vacuum pump **138**. During use, vacuum is provided to vacuum ports **134** and **136**. This vacuum evacuates the small space between exterior cylindrical surface **126** of rotary bottle transfer wheel **102** and interior cylindrical surface **128** of chamber **104**. Further, this vacuum evacuates bottle cutouts **107** and thus bottles **110** located within bottle cutouts **107**.

Accordingly, bottles **110** are continuously evacuated using a single vacuum pump **138** in accordance with this embodiment. Accordingly, the capital equipment and operation costs of rotary bottle vacuum transfer system **100** is minimized compared to a configuration where each bottle is treated independent of other bottles in an individual bottle reactor, requiring a duplication of pumping, gas and power systems.

Generally, atmospheric air leaking in through atmospheric port **106** is continuously removed through vacuum ports **134**, **136**. Accordingly, in one embodiment, pressure within chamber **104** adjacent vacuum ports **134**A, **136**A is greatest, pressure within chamber **104** adjacent vacuum ports **134**C, **136**C is least, and pressure within chamber **104** adjacent vacuum ports **134**B, **136**B is between the pressure adjacent vacuum ports **134**A, **136**A and the pressure adjacent vacuum ports **134**C, **136**C.

However, in another embodiment, residual process gas from bottle coating system **116**, e.g., leaking in though vacuum port **108** or trapped inside of bottles **110** is primarily removed through vacuum ports **134**C, **136**C. Accordingly, pressure within chamber **104** adjacent vacuum ports **134**C, **136**C may be greater than the pressure within chamber **104** adjacent vacuum ports **134**B, **136**B depending upon the volume of residual process gas being removed.

In accordance with one embodiment, different vacuum sources are coupled to vacuum ports **134**, **136**. For example, a first vacuum source, sometimes called a roughing pump, is coupled to vacuum ports **134**A, **136**A. This first vacuum source is designed to remove large volumes of air at a relatively high pressure. A second vacuum source, sometimes called a low-pressure vacuum pump, is coupled to vacuum ports **134**C, **136**C. This second vacuum source is designed to remove small volumes of air at a relatively low-pressure. Further, vacuum ports **134**B, **136**B are coupled to either the first vacuum source or the second vacuum source, or to a further third vacuum source.

FIG. **3** is a perspective view of a rotary bottle transfer wheel **102**A in accordance with one embodiment of the present invention. FIG. **4** is a cross-sectional view of a rotary bottle vacuum transfer system **100**A incorporating the rotary bottle transfer wheel **102**A of FIG. **3** in accordance with one embodiment of the present invention.

Referring now to FIGS. **3** and **4** together, rotary bottle vacuum transfer system **100**A includes a chamber **104**A. Chamber **104**A includes a base **402**, a cylindrical sidewall **404**, and a lid **406**. In one embodiment, base **402** and lid **406** are in the shape of disks although can be formed in any one of a number of shapes. Further, cylindrical sidewall **404** is in the shape of a hollow cylinder and includes vacuum ports **134**, **136** as discussed above. However, cylindrical sidewall **404** can be formed in any one of a number of shapes and typically includes an interior cylindrical surface **128**.

In one embodiment, base **402** is integral with cylindrical sidewall **404**, i.e., base **402** and cylindrical sidewall **404** are a single piece and not a plurality of separate pieces connected together. However, in another embodiment, base **402** and cylindrical sidewall **404** are separate pieces connected together with a vacuum seal in between, e.g., with an O-ring in between.

In accordance with this embodiment, lid **406** is a separate piece mounted, e.g., bolted, to cylindrical sidewall **404**. Lid **406** includes an annular seal surface **408** at a periphery of a lower surface **406**L of lid **406**. Further, cylindrical sidewall **404** includes a corresponding annular seal surface **410** at the top of cylindrical sidewall **404**. An O-ring **412** is located between annular seal surface **408** and annular seal surface **410** and forms a seal therebetween.

Rotary bottle transfer wheel **102**A is mounted on a vertical axle **414**. At a lower, e.g., first, end **414**L of axle **414**, axle **414** is coupled to a motor **416**. During use, motor **416** turns axle **414** and thus rotates rotary bottle transfer wheel **102**A.

Axle **414** extends through axle ports **418**, **420** of base **402**, lid **406**, respectively. Seals **422**, **424**, e.g., O-rings, form vacuum tight seals between axle **414** and base **402**, lid **406**, respectively. Thus, in accordance with this embodiment, chamber **104**A forms a vacuum tight enclosure around rotary bottle transfer wheel **102**A.

To further enhance the isolation of each of bottles **110** from one another, in accordance with one embodiment, at least one sliding seal between rotary bottle transfer wheel **102**A and chamber **104**A is used. More particularly, rotary bottle transfer wheel **102**A includes an exterior cylindrical surface **126**A. Exterior cylindrical surface **126**A extends from a bottom, e.g., first, surface **426** to a top, e.g., second, surface **428** of rotary bottle transfer wheel **102**A. Bottom and top surfaces **426**, **428** are circular in area.

Exterior cylindrical surface **126**A of rotary bottle transfer wheel **102**A includes a cylindrical lower, e.g., first, seal region **430** between bottle cutouts **107** and bottom surface **426**. Similarly, exterior cylindrical surface **126**A of rotary bottle transfer wheel **102**A includes a cylindrical upper, e.g., second, seal region **432** between bottle cutouts **107** and top surface **428**.

O-rings **434**, **436** form sliding seals between lower and upper seal regions **430**, **432** and interior cylindrical surface **128** of chamber **104**A.

In one embodiment, O-rings **434**, **436** are mounted within lower and upper seal regions **430**, **432**, respectively, for example, within O-ring grooves of lower and upper seal regions **430**, **432**. In accordance with this embodiment, O-rings **434**, **436** slide along interior cylindrical surface **128** of chamber **104**A.

In another embodiment, O-rings **434**, **436** are mounted within interior cylindrical surface **128** of chamber **104**A, for example, within O-ring grooves of interior cylindrical surface **128** of chamber **104**A. In accordance with this embodiment, O-rings **434**, **436** slide along lower and upper seal regions **430**, **432**, respectively, of rotary bottle transfer wheel **102**A.

Although one particular configuration of sliding seals to enhance the isolation of each of bottles **110** from one another is set forth above, in accordance with other embodiments, other sliding seals are used. For example, an O-ring **438** forms a sliding seal between bottom surface **426** and an upper, e.g., first, surface **402**U of base **402**. Similarly, an O-ring **440** forms a sliding seal between top surface **428** and lower surface **406**L of lid **406**.

O-rings **434**, **436**, **438** and **440** are examples of circumferential seals. More particularly, O-rings **434**, **436**, **438** and **440** are each located at fixed radial distances from axle **414** such that O-rings **434**, **436**, **438** and **440** lie on circumferences of circles when viewed from above.

In other embodiments, referring now to FIG. **3**, longitudinal seals are used. For example, longitudinal seals **442** extends vertically upwards between bottle cutouts **107**. Linear seals **442** are mounted to exterior cylindrical surface **126**A, e.g., within grooves. During use, linear seals **442** slide along interior cylindrical surface **128** of chamber **104**A and form seals between exterior cylindrical surface **126**A of rotary bottle transfer wheel **102**A and interior cylindrical surface **128** of chamber **104**A between each of bottle cutouts **107**.

In another embodiment, bottle cutout isolation seals are used. For example, referring to FIG. **3**, O-rings **444** are mounted to exterior cylindrical surface **126**A around the periphery of each of bottle cutouts **107**, e.g., within grooves. During use, O-rings **444** slide along interior cylindrical surface **128** of chamber **104**A and form seals between exterior cylindrical surface **126**A of rotary bottle transfer wheel **102**A and interior cylindrical surface **128** of chamber **104**A around each of bottle cutouts **107**.

Bottle cutouts **107** are rectangular openings in exterior cylindrical surface **126**A in accordance with this embodiment. More particularly, bottle cutouts **107** are spaced from and do not extend all the way to bottom surface **426** or top surface **428**. However, bottle cutouts **107** can be formed in other shapes such as that set forth below in reference to FIGS. **5**, **6** and **7**.

FIG. **5** is a perspective view of a rotary bottle transfer wheel **102**B in accordance with another embodiment of the present invention. FIG. **6** is a cross-sectional view of a rotary bottle vacuum transfer system **100**B incorporating rotary bottle transfer wheel **102**B of FIG. **5** in accordance with one embodiment of the present invention. Rotary bottle vacuum transfer system **100**B of FIG. **6** is substantially similar to rotary bottle vacuum transfer system **100**A of FIG. **4** and only the significant differences between rotary bottle vacuum transfer systems **100**A and **100**B are discussed below.

In accordance with this embodiment, bottle cutouts **107**A extend from bottom surface **426** to top surface **428** of rotary bottle transfer wheel **102**B. More particularly, bottle cutouts **107**A are slots in an exterior cylindrical surface **126**B extending longitudinally from bottom surface **426** to top surface **428**. Accordingly, rotary bottle transfer wheel **102**B is sometimes said to be in the shape of a gear.

FIG. **7** is a cross-sectional view of a rotary bottle vacuum transfer system **100**C incorporating the rotary bottle transfer wheel **102**B of FIG. **5** in accordance with another embodiment of the present invention. Rotary bottle vacuum transfer system **100**C of FIG. **7** is substantially similar to rotary bottle vacuum transfer system **100**A of FIG. **4** and only the significant differences between rotary bottle vacuum transfer systems **100**A and **100**C are discussed below.

Referring now to FIG. **7**, rotary bottle transfer wheel **102**B is mounted to a lid **406**A of a chamber **104**B. Accordingly, lid **406**A rotates along with rotary bottle transfer wheel **102**B. More particularly, during use, lid **406**A rotates relative to cylindrical sidewall **404** of chamber **104**B. Accordingly, O-ring **412**, e.g., a circumferential seal, forms a sliding seal between annular seal surface **408** of lid **406**A and annular seal surface **410** of cylindrical sidewall **404**.

In one embodiment, O-ring **412** is mounted within annular seal surface **408** of lid **406**A, for example, within an O-ring groove of annular seal surface **408**. In accordance with this embodiment, O-ring **412** slides along annular seal surface **410** of cylindrical sidewall **404**.

In another embodiment, O-ring **412** is mounted within annular seal surface **410** of cylindrical sidewall **404**, for example, within an O-ring groove of annular seal surface **410**. In accordance with this embodiment, O-ring **412** slides along annular seal surface **408** of lid **406**A.

FIGS. **8** and **9** are top and side schematic views of a bottle processing apparatus **800** in accordance with one embodiment of the present invention. Referring now to FIGS. **8** and **9** together, bottle processing apparatus **800** includes a rotary bottle vacuum transfer system **100**D mounted to a bottle coating system **116**. Rotary bottle vacuum transfer system **100**D transfers bottles **110** from atmospheric pressure into a sub-atmospheric pressure region within bottle coating system **116** as discussed above in reference to rotary bottle vacuum transfer system **100**. Rotary bottle vacuum transfer system **100**D is the same or similar to rotary bottle vacuum transfer system **100** and so is only briefly discussed below to avoid detracting from the principles of the invention.

Bottle coating system **116** includes a rotary coating mechanism that lifts bottles **110** onto a rotating gas inlet **902** that delivers the appropriate gases into the interior of the bottle **110**, and through a U-channel **904**, sometimes called a U-shaped channel, that is coupled to a power source **906**. Power source **906** is for applying electromagnetic radiation to U-channel **904** to generate a plasma inside of the bottle **110** and deposit a thin film coating with gas barrier properties.

As set forth above in reference to FIGS. **1-7**, rotary bottle vacuum transfer system **100**D includes either a cylindrical sliding seal in contact with a stationary outer wall or a cylindrical sliding surface in contact with a stationary outer seal in one embodiment. Rotary bottle vacuum transfer system **100**D provides a means for reducing the pressure of the bottle(s) **110** as they move into bottle coating system **116**, sometimes called the processing section. To achieve the pressure reduction, several pumping groups are positioned along the seals entering and exiting rotary bottle vacuum transfer system **100**D that pump away the residual atmospheric and process gases in one embodiment. Since there is a constant sealing surface, the pressure is reduced as the bottles **110** pass through rotary bottle vacuum transfer system **100**D.

Bottles **110** can either be held in-place (for example by the neck-of the bottle) through rotary bottle vacuum transfer system **100**D, or conveyed by an appropriate means. Once the bottle(s) **110** reach the transfer point, they are moved off of rotary bottle vacuum transfer system **100**D onto transfer wheel **120** that places the bottle(s) **110** into bottle coating system **116**.

Bottle coating system **116**, the processing section, includes arms **908** that grasps bottles **110** either by the neck (or other appropriate means) and lift the bottles **110** (through the use of a cam-type device that arms **908** ride on via a rotary mechanism that may include wheels) onto gas inlets **902** and mandrel assemblies. Gas inlets **902** provide a means to convey gases into the interior of the bottle **110** and to establish a processing pressure from which a plasma may be derived. The mandrel assembly provides a means to reduce the gas removal rate from the interior of the bottle **110** (thus establishing a higher pressure inside of the bottle **110** than outside) as well as a means to electrically isolate the bottle **110**. In one embodiment, the mandrel of the mandrel assembly is constructed from a polymeric or similar dielectric material. The mandrel assembly is discussed further below in reference to FIG. **11**.

Once the bottles **110** are lifted onto the gas inlet **902** and the pressure is established by the introduction of gases, the bottles **110** are transported (note that the bottles **110** are in continuous motion while being lifted onto the gas inlets **902**, for example, by a rotary mechanism) through U-channel **904**.

U-channel **904** is constructed by sandwiching a conductor (such as copper or silver-plated copper) between 2 layers of polymer (for example, a polymer like acetyl or ultra-high molecular weight polyethylene—both which exhibit very low water adsorption) to provide a capacitive means of coupling power from the radio frequency (13.56 Mhz) or lower frequency, for example 40 kHz, power source **906**, e.g., which includes a power supply and impedance matching unit, into the interior of the plastic bottle **110**. U-channel **904** is discussed in further detail below with reference to at least FIGS. **12**, **13** and **14**.

Gas inlet **902** inside of bottle **110** is grounded and acts as the return path for the electric field, allowing a plasma to be established and a thin film coating deposited on the interior surface of bottle **110**. Note that the design of gas inlet **902** is such that there are holes oriented along the length of gas inlet **902** (as discussed in greater detail below with reference to FIG. **11**) so that the gas is distributed evenly and uniformly into the interior of bottle **110**. In another embodiment, a gas inlet with an open end, e.g., a tube, is used. Further note that the gases can either be flowing continuously through gas inlets **902** (even when there is no bottle **110** being lifted or attached) to increase the life-time of gas inlets **902** by retaining gas flow through the holes. Or, alternatively, the gas flow through gas inlets **902** can be toggled on only when a bottle **110** is being lifted onto the gas inlet **902** and mandrel assembly.

The length (linear length as the bottle **110** moves along the arc established by the cylindrical shape of the mechanism holding the gas inlets **902**) of the U-channel **904** is selected based on the deposition rate of the process and desired coating thickness. Suitably, the length would be established by a deposition rate on the order of 50-500 Å/second and a desired coating thickness of 50-500 Å.

Once the bottle **110** exits U-channel **904**, which can either be configured as one long cylindrically shaped channel or segmented into smaller lengths (to allow several smaller power supplies to be utilized), the bottles **110** are lowered (again by the arm **908** that is holding the bottle **110** moving down the cam at the bottom of the bottle coating system **116**, sometimes called the chamber) and then transferred off of a coating wheel **910** of bottle coating system **116** onto transfer wheel **122** and finally onto rotary bottle transfer wheel **102** that delivers the bottle **110** back to atmospheric pressure and onto subsequent filling or storage.

Bottles **110** are coated using bottle processing apparatus **800** in a continuous assembly line fashion at a high rate. In one embodiment, bottles **110** are coated at a rate of at least 20,000 bph, e.g., 40,000 bph, thus maximizing the utilization efficiency of bottle processing apparatus **800**.

Further, bottles **110** are treated continuously in an assembly line fashion using common pumping, gas and power systems. This avoids duplication of costs and results in a significant decrease in process cycle time (defined as the time from when a bottle enters the machine until it exits with a thin film coating on the inside).

Although bottle processing apparatus **800** is illustrated and discussed above as including both rotary bottle vacuum transfer system **100**D and bottle coating system **116**, in one embodiment, the functionality of rotary bottle vacuum transfer system **100**D and bottle coating system **116** are combined into a single unit performing both functions.

FIG. **10** is a side schematic view of a bottle lift mechanism **1000** in accordance with one embodiment of the present invention. Referring now to FIGS. **8**, **9** and **10** together, once the bottles **110** are transferred from atmospheric pressure to vacuum (via rotary bottle vacuum transfer system **100**D), the bottles **110** are loaded onto coating wheel **910** of bottle coating system **116**. First, the bottle **110** is gripped at the neck **1002** (or in another appropriate manner) with a clip **1004** that holds the bottle **110** in place. The arm **908** that is attached to the clip **1004** is shaped in a right angle with a wheel **1006** at the bottom of the arm **908**.

The wheel **1006** rides along the bottom of the chamber on a cam **1008**, sometimes called a cam-type path, that lifts the arm **908** (and therefore the bottle **110**) up towards and onto the gas inlet **902** as the arm **908** and coating wheel **910** move in a rotary motion at the same rate as the transfer mechanism.

More particularly, referring now to FIG. **10**, a first bottle **110**A of the plurality of bottles **110** is in a lowered position **1010** as illustrated at the left of bottle lift mechanism **1000** and a second bottle **110**B of the plurality of bottles **110** is in an elevated position **1012** as illustrated at the right of bottle lift mechanism **1000**.

First bottle **110**A is secured to a first arm **908**A of the plurality of arms **908** by a first clip **1004**A of the plurality of clips **1004**. Bottle **110**A is directly aligned below a first gas inlet **902**A of the plurality of gas inlets **902**. Stated another way, gas inlet **902**A is concentrically aligned with bottle **110**A. Gas inlet **902**A is supported by a first mandrel assembly **1014**A of a plurality of mandrel assemblies **1014**. First arm **908**A, first gas inlet **902**A and first mandrel assembly **1014**A are all part of coating wheel **910** and move together as a single bottle coating station for processing bottle **110**A.

Gas inlet **902**A is coupled to a process gas supply line **1016**A of a plurality of process gas supply lines **1016**. During use, process gas is supplied to gas inlet **902**A through process gas supply line **1016**A, for example, from a common process gas source. In various embodiments, the process gas is a mixture including oxygen and organosilicon. See Felts, U.S. Pat. No. 6,112,695, issued Sep. 5, 2000, entitled "APPARATUS FOR PLASMA DEPOSITION OF A THIN FILM ONTO THE INTERIOR SURFACE OF A CONTAINER", herein incorporated by reference in its entirety, regarding suitable organosilicons.

Although a specific arrangement with first bottle **110**A is set forth above, in light of this disclosure, those of skill in the art will understand that a similar arrangement, sometimes called a bottle coating station, is provided for each bottle **110** as the bottle moves through bottle coating system **116**. In one embodiment, bottle coating system **116** includes 16 bottle coating stations.

Generally, each bottle **110** is secured to an arm **908** by a clip **1004**. Each bottle **110** is directly aligned below a gas inlet **902** supported by a mandrel assembly **1014**. Arms **908**, gas inlets **902** and mandrel assemblies **1014** are all part of coating wheel **910** and move together as processing stations for processing bottles **110**.

The gas inlets **902** are coupled to process gas supply lines **1016**. During use, process gas is supplied to gas inlets **902** through process gas supply lines **1016**, for example, from a common process gas source.

Referring still to FIG. **10**, rotation of coating wheel **910** causes bottle **110**A along with arm **908**A to move in the direction of an arrow **1018**. At the bottom of arm **908**A is a wheel **1006**A of the plurality of wheels **1006**. Wheel **1006**A rides along cam **1008**.

As shown in FIG. **10**, cam **1008** includes a slanted surface **1020**, sometimes called a ramp, which is angled with respect to the horizontal. Accordingly, as arm **908**A moves along cam **1008**, wheel **1006**A rolls along and is pushed up by slanted surface **1020** thus also moving arm **908**A and bottle **110**A up. More particularly, bottle **110**A is moved up and around gas inlet **902**A and more generally moved to an elevated position such as that of bottle **110**B. More particularly, bottle **110**B is shown in elevated position **1012** at the top of cam **1008**.

Although elevation of bottle **110**A from a lowered position to an elevated position is discussed above, in light of this disclosure, those of skill in the art will understand that bottles **110** are also moved from an elevated position to a lowered position using a cam in a similar but reverse manner. To illustrate, if bottle **110**B is moved in a direction opposite of arrow **1018** and down cam **1008**, bottle **110**B will move from elevated position **1012** to a lowered position such as lowered position **1010** of bottle **110**A.

Various embodiments for holding the bottles include holding the bottle by the neck with an external clip that is integrated into coating wheel **910**, sometimes called the spinning drum, holding the bottles from the base with an external cup type fixture that can be lifted and lowered, and holding the wall of the bottle in an appropriate manner. As discussed above, embodiments of the lifting mechanism include an arm or elevator-type lifting mechanism, either of these could incorporate all of the holding mechanisms discussed above. In an alternative embodiment, the lifting mechanism pushes the bottle from the base (this saves space in the apparatus by eliminating the need to have an arm that rises above the coating wheel).

FIG. **11** is a cross-sectional view of a bottle **110** in an elevated position **1012** around a gas inlet **902** in accordance with one embodiment of the present invention. In accordance with this embodiment, coating wheel **910** includes a top plate **1102**. Top plate **1102** is mounted to an axle **1104** which rotates coating wheel **910** and top plate **1102**. Illustratively, axle **1104** is driven by its own motor or is coupled to the motor of rotary bottle vacuum transfer system **100**D (see, for example, motor **416** of FIG. **4**) through appropriate mechanical means.

Top plate **1102** includes a mandrel cutout **1106** into which a mandrel **1108** is mounted. Bottle **110** is fitted into a cylindrical opening **1110** in mandrel **1108** and top plate **1102** of coating wheel **910**. Opening **1110** is part of mandrel **1108** which is polymeric (although the rest of coating wheel **908** may either be made from a polymer or a metal).

In accordance with this embodiment, mandrel **1108** is a "puck" type design which is screwed (or similarly) attached to top plate **1102** so that bottle changeovers can be accomplished readily. Mandrel **1108** is a dielectric electrically isolating bottle **110** from coating wheel **910** and bottle coating system **116**. Further, arm **908** and/or clip **1004** is a dielectric also electrically isolating bottle **110** from coating wheel **910** and bottle coating system **116**.

Note that the process gas is flowing continuously through gas inlet **902** in one embodiment. Gas inlet **902** includes a plurality of gas distribution outlets **1118**, sometimes called holes, for uniform distribution of the process gas within bottle **110**. The process gas is typically mixed (organosilicon and oxygen for example) outside of the chamber as set forth in Felts, U.S. Pat. No. 6,112,695, cited above. This insures good distribution of the process gas and simplifies the gas distribution system.

The complete mandrel assembly **1112** includes mandrel **1108** and a screen **1114** on the top side of mandrel **1108**. Gas inlet **902** passes through an opening in screen **1114** and in one embodiment, is supported by screen **1114** and thus mandrel assembly **1112**. Gas inlet **902** also passes through cylindrical opening **1110** in mandrel **1108**.

Screen **1114** acts as a plasma screen (thus eliminating plasma ignition outside of the bottle). More particularly, screen **1114** is porous allowing process gas to flow through screen **1114**. However, screen **1114** restricts the flow of process gas out of bottle **110** thus causing the pressure inside of bottle **110** to be greater than the pressure outside bottle **110**. Since the pressure inside bottle **110** is greater than outside bottle **110**, the process gas concentration inside bottle **110** is also greater than outside bottle **110**. Do to this increased pressure and process gas concentration inside bottle **110**, the plasma is preferentially generated inside of bottle **110**.

Gas inlet **902** is attached to process gas supply line **1016** of the gas distribution system via a gas coupler **1116**. Gas coupler **1116** allows gas inlet **902** to be plugged in and out for ease of maintenance and changeover.

Once bottle **110** is lifted onto gas inlet **902** as discussed above in reference to FIG. **10**, bottle **110** continues onto the U-channel for coating as discussed in greater detail below with reference to FIGS. **12**, **13** and **14**.

FIG. **12** is a cross-sectional view of a bottle **110** within U-channel **904** in accordance with one embodiment of the present invention. FIG. **13** is an enlarged cross-sectional view of the region XIII of U-channel **904** of FIG. **12**. FIG. **14** is a schematic top view of U-channel **904** of FIG. **12** in accordance with one embodiment of the present invention.

Referring now to FIGS. **12**, **13** and **14** together, after the bottles are lifted onto the gas inlet and into the mandrel in the top plate of the coating wheel as discussed above in reference to FIGS. **10** and **11**, the bottles continue in a rotary motion into the coating section **1200** of bottle coating system **116**.

Coating section **1200** includes a powered U-channel **904** that is constructed from a polymer/metal/polymer laminate in one embodiment. For example, referring to FIG. **13**, U-channel **904** includes an inner dielectric layer **1302**, e.g., a polymer, an outer dielectric layer **1304**, e.g., also a polymer, and a conductive layer **1306**, e.g., metal. Conductive layer **1306** is electrically connected to a power source conductor **1308**, sometimes called an RF feed.

In one embodiment, an interior surface **1310** of U-channel **904** is polymeric, e.g., inner dielectric layer **1302** is a polymer or coated with a polymer. By forming interior surface **1310** to be polymeric, any friction and heating of the bottle surface of bottle **110** in contact with U-channel **904** is reduced. Tolerances is maintained to keep bottle **110** within approximately 1/16" of interior surface **1310** of U-channel **904** and no more than 1/4" in one embodiment.

Interior surface **1310** of U-channel **904** includes an outer sidewall **1212**, an inner sidewall **1214**, and a base **1216**. Generally, outer sidewall **1212** and inner sidewall **1214** are vertical cylindrical surfaces and base **1216** is a horizontal annular surface extending from inner sidewall **1214** to outer sidewall **1212**.

During use, conductive layer **1306** is powered by an external power source **906**. More particularly, U-channel **904** receives its power from a power source **906** through a stationary power feedthrough **1202** that can deliver power from 40 kHz to 13.56 MHz or higher frequencies as appropriate. Stationary power feedthrough **1202** forms a vacuum tight seal with an outer wall **1204** of bottle coating system **116**. Stationary power feedthroughs such as stationary power feedthrough **1202** are well known to those of skill in the art and so is not discussed in further detail to avoid detracting from the principles of the invention.

The connection to U-channel **904** from power feedthrough **1202** is achieved either through a mechanical coupling or by soldering a copper strap between the two. For example, in one embodiment, power source conductor **1308** is a copper strap electrically connected to power feedthrough **1202**.

In one embodiment, power source **906** includes a power supply **1206**, e.g., an AC power supply, and an impedance matching network **1208**. Power supplies and impedance matching networks such as power supply **1206** and impeding matching network **1208** are well known to those of skill in the art and so are not discussed in detail to avoid detracting from the principles of the invention.

In one embodiment, power feedthrough **1202** is connected to impedance matching network **1208** in as close proximity as possible. Impedance matching network **1208** is connected to power supply **1206** via a simple coaxial cable. To complete the electrical circuit, power supply **1206** is also electrically coupled to gas inlet **902**, which operates as a counter electrode for power supply **1206**.

As illustrated in FIG. **12**, U-channel **904** is U-shaped. However, in another embodiment, interior surface **1310** of U-channel **904** corresponds in shape to bottle **110**. More particularly, interior surface **1310** has the identical shape as the exterior surface of bottle **110**, but is slightly larger than bottle **110** to avoid contact with bottle **110**. Stated another way, interior surface **1310** is shaped to mimic the outside dimensions of the particular bottle, for example a "hoop-skirt" design found in COCA-COLA® bottles as illustrated in FIG. **16**. The channel section (or sections) are easily removed from the chamber so that bottle size and shape changeovers are simplified.

FIG. **16** is a cross-sectional view of a hoop-skirt bottle **1610** within a U-channel **904**A in accordance with another embodiment of the present invention. U-channel **904**A includes an inner dielectric layer **1302**A, e.g., a polymer, an outer dielectric layer **1304**A, e.g., also a polymer, and a conductive layer **1306**A. Interior surface **1310**A of U-channel **904**A corresponds in shape to hoop-skirt bottle **1610**. In accordance with this embodiment, inner dielectric layer **1302**A and conductive layer **1306**A also correspond in shape to hoop-skirt bottle **1610**.

Referring again to FIG. **12**, inside of bottle coating system **116**, referred to as the chamber for simplicity, U-channel **904** is supported by a U-channel support block **1210**. In one embodiment, U-channel support block **1210** includes a polymeric material (either in a singular block or multiple blocks) that acts to shield the remaining chamber and as a means of significantly reducing the interior volume of the chamber. The reduction of chamber volume provides a benefit to the overall operation of the apparatus, since pumping speed requirements will be significantly reduced. The type of polymer of U-channel support block **1210** typically has a low water uptake and stability at moderate temperatures. Illustrative polymeric materials, e.g., for inner dielectric layer **1302**, outer dielectric layer **1304**, and U-channel support block **1210**, include acetyl (DELRIN™) or ultra-high-molecular-weight polyethylene (UHMWPE) or similar material. Cam **1008** discussed above in FIG. **10** is integrated, e.g., a part of, U-channel support block **1210** in one embodiment simplifying the design further. Two cams **1008** for raising and lowering bottles **110** are illustrated in FIG. **14** as an example.

Referring now to FIG. **14**, U-channel **904** is one large cylindrically shaped channel in one embodiment. More particularly, a radius R to the center of U-channel **904**, i.e., the circumferential path **1402** along which bottles **110** travel, equals the distance Y (FIG. **9**), sometimes called the radius, of gas inlets **902** from axle **1104**. Stated another way, circumferential path **1402** lies on the circumference of a circle equidistant from outer sidewall **1212** and inner sidewall **1214** and having radius R.

In one embodiment, U-channel **904** includes a plurality of U-channels **1404**A, **1404**B, **1404**C, **1404**D, collectively

U-channels **1404**, electrically isolated from one another. Further, each U-channel **1404**A, **1404**B, **1404**C, **1404**D has its own power source **906**A, **906**B, **906**C, **906**D, respectively. In this manner, the power input to each U-channel **1404** is independently controlled.

By using several smaller U-channels **1404**, varying power levels are allowed to be applied to the plasma in real-time and the inclusion of redundancy in the apparatus insuring maximum mean-time-between-failure (MTBF).

FIG. **15** is a cross-sectional view of a bottle **110** having a barrier coating **1502** deposited on an interior surface **1504** of bottle **110** in accordance with one embodiment of the present invention. Barrier coating **1502** is deposited using bottle processing apparatus **800** as discussed herein. Barrier coating **1502** is located on the interior surface **1504** of bottle **110**. Barrier coating **1502** is deposited through the plasma decomposition of a 2 component gas including an organosilicon and oxygen in one embodiment. Illustrative organosilicon materials include hexamethyldisiloxane and 1,1,3,3-tetramethyldisiloxane. The organosilicon material provides the Si—O—Si linkage which is then combined with oxygen to yield silicon dioxide or sub-oxides (depending on the ratio of oxygen to organosilicon gas that is flowed into the chamber and the power level).

Barrier coating **1502** includes small amounts of carbon (up to approximately 3%) in one embodiment. In accordance with this embodiment, barrier coating **1502** is designated as SiOCH and provides greater ductility if the application requires that barrier coating **1502** have elasticity.

FIG. **17** is a cross-sectional view of a bottle **110** in an elevated position **1012** around a gas inlet **902**B in accordance with yet another embodiment of the present invention. FIG. **18** is a cross-sectional view of bottle **110** of FIG. **17** within a U-channel **904**B in accordance with one embodiment of the present invention. Referring now to FIGS. **17** and **18** together, a bottle coating system **116**A for simultaneously forming a barrier coating on the exterior and/or interior surfaces of the bottle **110** is illustrated. Bottle coating system **116**A of FIGS. **17** and **18** is similar to bottle coating system **116** of FIGS. **11** and **12** and only the significant differences between bottle coating system **116**A and bottle coating system **116** are discussed below.

As shown in FIGS. **17** and **18**, bottle coating system **116**A includes at least one exterior gas inlet, e.g., two exterior gas inlets **1702**, outside of bottle **110** and gas inlet **902**B inside bottle **110**. Although two exterior gas inlets **1702** are illustrated, in one embodiment, two additional exterior gas inlets **1702**, i.e., for a total of four exterior gas inlets **1702**, in front of and behind bottle **110** are used to insure uniform gas distribution around the outside of bottle **110**.

Exterior gas inlets **1702** allow gas to be diverted to the outside of bottle **110** (by dividing the flow between interior gas inlet **902**B and exterior gas inlets **1702**) for subsequent coating. In the same manner as described in FIG. **10** above, bottle **110** is lifted up to the gas inlets **902**B, **1702** by the lifting arm **908**. Depending on the location of the exterior gas inlets **1702** and arm **908**, in one embodiment, a hole **1710** is provided in arm **908** that allows the exterior gas inlets **1702**, e.g., the inside inlet, to not interfere with arm **908**.

In another embodiment, interior gas inlet **902**B is not used. In accordance with this embodiment, bottle coating system **116**A only forms a barrier coating on the outside of bottle **110**. Specific applications include those that require the exterior surface to have specific properties such as low surface energy (non-wettable) which was demonstrated previously with silicon oxide coatings produced from organosilicon materials.

To accommodate the gas inlet system including exterior gas inlets **1702**, U-channel **904**B is shaped to prevent U-channel **904**B from contacting exterior gas inlets **1702** as illustrated in FIG. **18**. This is readily achieved by enlarging the U-channel (polymer/metal/polymer) structure and decreasing the volume of the polymeric blocks described earlier. The remaining attributes of the bottle coating system **116**A as described previously would be the same.

The drawings and the forgoing description gave examples of the present invention. The scope of the present invention, however, is by no means limited by these specific examples. Numerous variations, whether explicitly given in the specification or not, such as differences in structure, dimension, and use of material, are possible. The scope of the invention is at least as broad as given by the following claims.

What is claimed is:

1. A system comprising:

a plurality of gas inlets;

a top plate mounted to an axle;

mandrel assemblies for supporting said gas inlets mounted in mandrel cutouts of said top plate;

a bottle lift mechanism for lifting bottles around said gas inlets and into said mandrel assemblies;

a U-channel having a cylindrical shape such that a radius to a center of said U-channel equals a distance of said gas inlets from said axle, said U-channel comprising a vertical cylindrical outer sidewall concentric with said center of said U-channel and having a first radius from said axle, a vertical cylindrical inner sidewall concentric with said outer sidewall and having a second radius from said axle less than said first radius, and a horizontal annular base extending from said inner sidewall to said outer sidewall.

2. The system of claim **1** further comprising:

a chamber comprising an interior cylindrical surface;

at least one vacuum port in said interior cylindrical surface; and

a rotary bottle transfer wheel within said chamber, said rotary bottle transfer wheel comprising:

an exterior cylindrical surface directly adjacent said interior cylindrical surface of said chamber; and

bottle cutouts in said exterior cylindrical surface.

3. The system of claim **2** wherein said chamber comprises an atmospheric port and a vacuum port.

4. The system of claim **2** wherein said interior cylindrical surface comprises a pressure reduction section and a pressure increasing section.

5. The system of claim **4** wherein said at least one vacuum port comprises a first vacuum port in said pressure reduction section and a first vacuum port in said pressure increasing section.

6. The system of claim **4** wherein said at least one vacuum port comprises a plurality of vacuum ports in said pressure reduction section and a plurality of vacuum ports in said pressure increasing section.

7. The system of claim **1** further comprising a vacuum pump coupled to said at least one vacuum port.

8. The system of claim **1** wherein said chamber further comprises:

a base;

a cylindrical sidewall comprising said interior cylindrical surface; and

a lid.

9. The system of claim **8** wherein said lid comprises an annular seal surface and wherein said cylindrical sidewall comprises an annular seal surface, said system further comprising a seal between said annular seal surface of said lid and said annular seal surface of said cylindrical sidewall.

10. The system of claim **1** wherein said rotary bottle transfer wheel is mounted on an axle, said system further comprising a motor for rotating said axle and said rotary bottle transfer wheel.

11. The system of claim **1** further comprising:

at least one sliding seal between said rotary bottle transfer wheel and said chamber.

12. The system of claim **11** further comprising a power source coupled to said U-channel.

13. The system of claim **12** wherein said power source is further coupled to said gas inlets.

14. The system of claim **11** wherein said bottle lift mechanism comprises:

arms comprising wheels;

clips for grasping said bottles attached to said arms; and

a cam upon which said wheels ride.

15. The system of claim **14** wherein said cam comprises a slanted surface.

16. The system of claim **11** wherein said mandrel assemblies comprise:

mandrels;

screens at a top of said mandrels.

17. The system of claim **16** wherein said mandrels comprise a dielectric material.

18. The system of claim **16** wherein said screens restrict a flow of process gas out of said bottles.

19. The system of claim **11** wherein an interior surface of said U-channel corresponds in shape to said bottles.

20. The system of claim **11** further comprising:

a rotary bottle vacuum transfer system for taking said bottles from atmospheric pressure and transferring said bottles to a bottle coating system at a sub-atmospheric pressure in a continuous assembly line fashion; said bottle coating system comprising:

said plurality of gas inlets;

said top plate mounted to said axle;

said mandrel assemblies;

said bottle lift mechanism;

said U-channel, wherein said bottle coating system is for forming a thin film coating having barrier properties on at least one surface of said bottles in said continuous assembly line fashion.

21. The system of claim **20** wherein said rotary bottle vacuum transfer system is further for returning said bottles from said sub-atmospheric pressure region of said bottle coating system back to said atmospheric pressure in said continuous assembly line fashion.

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